UNIVERSITY OF ALBERTA

A HYDROLOGIC BUDGET FOR THE VAUXHALL DISTRICT OF THE BOW RIVER IRRIGATION PROJECT

by

© NAGENDRA NATH KHANAL

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF AGRICULTURAL ENGINEERING

EDMONTON, ALBERTA

Spring 1969

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A Hydrologic Budget for the Vauxhall District of the Bow River Irrigation Project" submitted by Nagendra Nath Khanal in partial fulfillment of the requirements for the degree of Master of Science.

ACKNOWLEDGEMENT

Sincere thanks to Dean F.V. MacHardy, my supervisor, who gave me this golden opportunity to work under him and who gave his valuable advice and encouragement to complete this thesis.

Sincere thanks also to Professor Egon Rapp of the Department of Agricultural Engineering and to Dr. J.C. Van Schaik who spent hours of their valuable time making suggestions on the technicality and the format of this thesis. Without their suggestion, encouragement and the brotherly advice of the above, this thesis would not have been completed.

Thanks also to Professor T.A. Preston of the Department of Agricultural Engineering who went over the thesis page by page before the final typing and visited the Research Station many times while the research was in progress and gave the moral support and the encouragement to complete the work. Thanks also to all the Members of the Department of Agricultural Engineering and to the Members of the Research Station who were always at hand to help in time of need. Thanks to Dr. D.C. McKay, Mr. H. Hobbs and Mr. K. Krogman, all of the Agricultural Research Station Lethbridge for their valuable time spent in discussing some of the topics of the thesis.

Finally thanks to Miss E. Symons who typed the thesis and to Mr. Robert Stout and to Miss Gail Williams for the final proof reading.

ABSTRACT

The purpose of this investigation was to develop a hydrologic budget for the Vauxhall District of the Bow River Irrigation Project for the 10-year study period 1957 - 1966 inclusive. The main items of supply of the hydrologic budget of an irrigation project consist of gross diversion and precipitation, for which the data for the 10-year study period was available. The items of disposal consist of consumptive use by crops, the surface waste, evaporation and evapotranspiration by natural vegetation, seepage and deep percolation from the Main Canal, conveyance, delivery and farm use. For the items of disposal, data on the land use, consumptive use and return flow were available, and an estimate was made for any figures that were not available.

1. It is found from this investigational study that approximately 88 percent of the gross diverted water reaches the delivery canals, and out of this, 68 percent is available to farmers. So a loss of 32 percent of the diverted water is encountered in the conveyance system.

2. Considering items of supply to be 100 percent, it was found that 64.7 percent of this could be used by crops for their optimal growth. The remaining 35.3 percent of the items of supply consists of 24.6 percent surface return flow, 7.2 percent seepage and deep percolation and 3.5 percent evaporation and evapotranspiration.
3. Data on the measured return flow was compared with the estimated return flow. The measured return flow as a percentage of the items of supply, on the average, for the 10-year study period was found to be 19.7 percent. The measured return flow was 84 percent of the estimated return flow.
4. Some of the items of the hydrologic budget were correlated. Precipitation vs gross diversion showed a negative correlation with a coefficient of -0.63 which is not significant. Items of supply vs total losses showed a positive correlation coefficient of 0.80 which is significant. Farm delivery plus precipitation vs total losses showed a positive correlation with a coefficient of 0.69. Gross diversion vs total losses correlated significantly with a coefficient of 0.91 and the total irrigation loss vs measured return flow showed a coefficient of 0.66 which is not significant.

5. Estimates of variances for gross delivery as a percentage of gross diversion was found to be 88.6 ± 3.8 percent and farm delivery as a percentage of gross diversion was found to be 68.2 ± 6.3 percent.

6. The most important factor in designing a new irrigation project or improving an old project is to know how much water is needed for the optimal growth of a crop, and how much has to be diverted to supply that amount. From this study it was found for the Vauxhall District, on the average, 64.7± percent of the total amount of water supplied can be used consumptively by the crops for their optimal growth while the remainder is considered as loss. It is believed that this will give good information for irrigation designers and planners of water use in Alberta.

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INTRODUCTION

Economic and social development of a country is entirely dependent upon the achievement of increased agriculture production. This often requires the opening of additional lands to agriculture through new irrigation projects or the improvement of existing irrigation systems and practices to ensure efficient use of water and continued productivity. In the past, proper management and control of water was not always emphasized as it was thought that there was still enough water for various kinds of development. But now with the population explosion, and the shortage of food, the demand for water for irrigation has increased tremendously in every part of the globe.

Water development projects are undertaken in order to fulfill this demand. Irrigation projects can only be successful if adequate and reliable hydrologic data is available. The basic data required for the development of projects are the amount of water required for irrigation,precipitation, the water that returns to the river as surface and subsurface flow and water retained on the project.

This research is an investigation and analysis of hydrologic data available for the Vauxhall District of the Bow River Project in southern Alberta. The demand for water for irrigation purposes has been increasing on this project and in the near future the irrigated acreages will probably be increased. The topic of this

thesis was suggested by the Lethbridge Research Station.

The objective of this research will therefore be:

1. To make a comprehensive study of all the hydrologic aspects of the area under investigation,
2. To investigate the uses of water in the project area,
3. To establish relationships between land use, precipitation, runoff, and water table fluctuation,
4. To establish a relationship between the hydrological factors and the physiographic characteristics of the project.

These are the major objectives but there are still many factors and items that need to be investigated and evaluated by further research and investigation.

REVIEW OF LITERATURE

When early civilizations grew up along river banks, floods caused much damage to the people living in these areas. So they started the study of water in its natural state and found some crude way of protecting their cities by making flood walls. The first hydrological principles were extremely crude because man was interested only in controlling nature rather than understanding it. Hydrology as a science started only after the seventeenth century. The hydrologic cycle was fully understood by Leonardo da Vinci (1452-1519) and Bernard Pallissy (1509-1589). But there was little contribution from them on the quantitive aspects (29).

During the seventeenth century the works of Pierre Perrault (1608-1680), Edme Mariotte (1620-1684) and Edmond Halley (1656-1742) were published. Perrault measured rainfall during a three year period, and roughly estimated the drainage basin on the River Seine above a point in Burgundy as well as the runoff at that point. He also conducted experiments on the natural evaporation of water. Understanding of ground water movement and its flow started only during the nineteenth century (51).

Many people have devoted their life work to the study of hydrology. The great expansion of activity in flood control, irrigation, soil conservation and related fields which began about 1930, gave the first real impetus to organized research

in hydrology, and the need for more precise design data became evident (31). The concept of modern hydrology started during that period. Later during the 1950's computers brought a new, powerful tool to the hydrologists. Among a few, Sugawara (48) hypothecated a complex system of linear storages and delays by successive trials, and adjusted the system until the rainfall input could be transformed to the system flow output in the computer. Analog approaches were explored by Bagley (6). In the coming years, there will be more remarkable contributions in this important field of hydrology. World-wide projects on hydrology are being sponsored by the International Hydrologic Decade. After the completion of this decade, more knowledge will be available on the various aspects of hydrology.

The Hydrologic Budget

A hydrologic budget is defined as "An accounting of the inflow to, outflow from, and storage in, a hydrological unit such as a drainage basin, aquifer,soil zone, or irrigation project"(59). The hydrologic budget is simply a statement of the conservation of water in that what comes into a project area, has to balance with what goes out plus what remains in the project area (1).

A slightly modified form of the hydrologic budget items that would apply to an irrigation project would be as follows.

Table 1:

Items of supply	Items of disposal
Gross diversion and Precipitation	Consumptive use and Irrigation losses[1]

[1] Irrigation losses includes those losses in conveyance, delivery and on the farm due to evaporation, seepage and deep percolation (ground water) and surface waste. All surface waste and part of the subsurface flow which returns as measured flow is termed as surface return flow. Measured return flow

does not always agree with the estimated return flow.

In mathematical terms:

$$G_D + P = C_U + I_L$$

where,

G_D = Gross diversion of water to the project area,

P = Precipitation in the project area,

C_U = Consumptive use,

I_L = Irrigation losses.

Many of the items in the hydrologic budget cannot be measured directly, particularly groundwater and evapotranspiration but nevertheless with good judgement, a good estimate can be made (1).

Water budget studies have been made on a regional basis in the United States by the U.S. Geological Survey. They are published in various water supply papers (55,56,57,58). In those works some items, namely the subsurface inflow and outflow part has been neglected, assuming that they are equal. Lewis and Burgy (32) made a complete water budget study for an experimental watershed and reported that the ground water component provides a considerable insight into the redistribution of rainfall. They had 24 observation wells under study to find the effect of changes in groundwater and ground water flow. Kalinin and Mararova (28) and Krestovskity (30) made a complete water budget study of a small drainage basin during the period of spring high water and found the contribution of precipitation to the runoff pattern.

Courage and de Martonne (49) found the difference between precipitation and runoff amounting to 350mm for Sweden, 600mm for Central Italy and 500mm for France from their water budget study.

Since the return flow is a fairly large portion of the items of supply, it is of invaluable benefit and importance to the downstream users. Some work has been done on this aspect of the hydrological budget. Hauk reports in his book "Irrigation Engineering"(20) that the return flow for the three districts of the Rio Grande Projects are of the order of 50.3 percent of the gross diversion, averaged for a period of seven years. The Canada Department of Energy, Mines and Resources has made a comprehensive study of the return flow from the Eastern, Western and the Bow River Projects (12,13). On the basis of 0.5 percent of precipitation as runoff, for the Bow River Irrigation Project the return flow as percentage of diversion for the years 1957 to 1965 inclusive, varied from 17% to 28%, the average being 19.8%. For the Western Irrigation District, it varied from 29% to 109% , the average being 49.4%. For the Eastern Irrigation District 19% to 32%, the average being 24.7%. The underground part of the return flow was not taken into consideration due to the incomplete knowledge of the subsurface part of the total return flow.

Theoretically, the items of supply equal items of disposal in the hydrologic budget. However, there will always be a difference between them. Thus judgement is an important factor

in synthesizing a hydrologic budget and most such budgets are properly in the realm of the scientific hypothesis. Even so, they may be generally accepted by other hyrologists. A hydrologic inventory is the right term for the process of evaluating the items in the budget and balancing the hydrologic budget equations′(1).

Basic Data

In synthesizing a hydrologic budget, the following basic data are required.

Diversion of irrigation water

Gross diversion is the total amount of water diverted from a source of supply in any one year to satisfy all the demands of an irrigation project (2).

It is man's method of partially overcoming deficiencies in the natural pattern of precipitation, unfavourable seasonal distribution for normal plant growth or introduction of plant species which can take advantage of favourable soil or temperature conditions but require more water than is usually provided (3, P25). The main source of water diverted for irrigation is the excess of snow and rainfáll in an area where it is not used consumptively. The excess water is stored in surface reservoirs built to store water for irrigation use when the natural flow of a stream is not sufficient to meet irrigation demands (24). Winter and spring runoff are impounded until needed for crop growth. The water diverted for distribution to an irrigation project is determined for a specified

percentage chance, usually 80 percent, which means that the irrigation project will have sufficient water 4 out of 5 years. A considerable quantity may be unused because the irrigated acreage or the number of irrigations per season varies from year to year (39).

To make water flowing in a stream available for irrigation use, it must be diverted by means of a diversion dam or headworks. Primitive and early irrigation developments used such works to divert the natural unregulated streamflow directly into project canals. Today, diversions are usually coordinated with upstream storage in order to make the maximum use of the available stream flow.

A diversion dam is constructed across an existing stream to raise its water level to a controllable elevation from where it can flow by gravity through a diversion canal to the irrigation area, using only the direct stream flow (67). The approximate location of a diversion dam or heading is usually established by the overall requirements of the project plan. The location of the diversion determines to some extent the amount of water that will be available to the project (3).

The basis of storage calculations is the mass curve technique, which may be applied with or without consideration of the sequence of low flows. Either graphic or arithmetic procedures may be used (38). The most common form of this method involves the determination of storage volumes required

for all low flow periods and the array and plotting of these volumes to determine frequencies at which stated storage values are required (23).

The area behind the dam, called a reservoir, is required to attain full utilization of most streams. The primary purpose of reservoir storage is to regulate the stream so that the natural flow can be adjusted to meet as nearly as possible, the rate demand of water for irrigation. Irrigated lands are often located great distances from the sources of water supplies or storage reservoirs. Water obtained from natural streams and from surface reservoirs has to be conveyed to these areas. The most common types of irrigation conveyance channel is the one excavated in natural material along the line that water must be conveyed. When used without artificial lining of bed or sides, such a channel is called an earth canal. The low initial cost constitutes the major advantage of earthen canals.

In determining the capacity of canals to be used for irrigation water diversion, the approach should be made from the view point of water use.; first to determine the requirement of water deliveries at the farm headgate, and second to determine the losses encountered in transit to the headgate. The canals have to be designed for peak demand which usually is 10-15 percent greater than the regular seasonal demand (26). The demand for irrigation water fluctuates from year to year due to many reasons. Demand fluctuation has an inverse correlation with the precipitation. If in a year the precipitation is above normal then less diversion is required. If crops which require

higher amounts of water for optimal growth are grown, the water demand becomes higher.

Only part of the diverted water is available for crop use. Blaney and Criddle (8) estimate that only 30 percent of the total water diverted from a source of supply becomes available for use by crops, the remaining 70 percent is the total irrigation loss. The U.S. Bureau of Reclamation (63) records show that out of 15,650,000 ac-ft of water diverted on 46 of its irrigation projects, one-fourth or 3,900,000 ac-ft is lost. Sylvester (47) reports that out of an average water diversion of 6.6 ac-ft per acre per year from the Yakima River Basin, only 4.25 ac-ft per acre could be measured at the farm headgate, the other being the diversion loss from canals. Underhill (2) reports that for the Bow River Development under the present situation, for a net irrigation requirement of 1.04 ac-ft per acre, the gross diversion is 2.90 ac-ft per acre and for the Eastern Irrigation District for a net water requirement of 12.5 inches for consumptive use, assuming the farm efficiency to be 60%, the gross diversion required is 34.9 inches.

For certain farm delivery requirements, the losses and waste inherent in the operation of a conveyance system has to be added in order to determine the diversion requirements (3, Chap 59). Losses and waste from an open canal depends on the type of material in which they are constructed, whether they are lined, their length, and the physical control of the water

in the system itself. Losses and wastes from lengthy conveyance facilities may be as high as 40 percent (3, Chap 59).

Precipitation

Precipitation is the term used to denote the total amount of rain or snow that fell on the ground during a certain period. It is the basic source of water, and its occurrence is irregular and to date, practically uncontrollable. Fortunately nature provides a basic system of control, and man to this adds his own development. Surface runoff is one part of the hydrologic cycle which also includes precipitation, evaporation, evapotranspiration, transpiration and storage in streams, lakes, and ground water reservoirs.(24).

An average precipitation of about 30 inches in the form of snow and rain falls each year in the United States. About 21.5 inches or about 72 percent of the total is evaporated from land and water surfaces or transpired from natural or dry-land vegetation. Of the remaining 8.5 inches, about 6 percent evaporates while 22 percent is used by man, and joins the unused portion to make a total of about 8 inches discharging into the oceans under present conditions (33).

Some form of precipitation such as rain or snow is the ultimate source of all soil water, ground water or stream flow whether from direct surface runoff, intermediate storm runoff, return flow, or ground water storage. Ground water recharge

and stream flow are residuals after soil water deficits are replenished. In addition to the kinds, amounts, and the characteristics of precipitation, the residual is intimately related to many factors such as soil, geology, topography, climate and vegetation (3, P1089).

The character and distribution of total precipitation over an area must be considered from at least two viewpoints depending on the purpose for which the information is needed. First, the total annual supply and its fluctuation must be examined to determine needs for reservoir storage so that there will be optimal benefits from delayed use. Secondly, the probability distribution of certain values on a seasonal or monthly basis must be considered in order to plan intelligently for the use of the available water supply and for balancing of various user demands. Competitive uses for the total water supply include irrigation, municipal water supply and industrial uses (9). To these have to be added reservoir evaporation and seepage losses. The consumptive use must then be balanced against the distribution of total precipitation for complete understanding of the water budget (40).

Precipitation only in a few locations will fulfill the water requirement of crops at all times to produce maximum yields. The failure of precipitation to meet these requirements results in increasing need for irrigation in arid and semi-arid areas (24).

Climate is a major factor in determining the benefits derived from irrigation in an area (15). Climate, in a broad sense, includes annual precipitation and its seasonal distribution, humidity, air movement, temperature and light. Whether greater or more desirable growth will result from the application of additional water is usually directly correlated with the moisture deficit of the area - a function of precipitation and evaporation. Temperature and the length of the growing season are also important in assessing the desirability of irrigating in an area.

Precipitation measurements are subject to various errors, most being individually small but with a general tendency to yield measurements that are too low (31).

In regions with appreciable variation in elevation and other climatic factors some expression has to be given to such physiographic parameters as elevations, slope, orientation, exposure and environment (22).

Precipitation to be of beneficial use should have the following characteristics (24).

1. Amount should be sufficient to replace moisture depleted from the root zone.
2. Frequency should be often enough to replenish the soil moisture before plants suffer from the lack of moisture.
3. Intensity should be low enough, so that water can be absorbed by the soil.

The general method of measurement of precipitation is by rain gauge (29). The exact volume of precipitation measured depends on the network of precipitation gauges available. The number of precipitation stations required can be calculated by statistical techniques (65). Precipitation data from recording, non-recording and storage gauges are a necessity in planning and development of surface water supplies and operating irrigation projects utilizing surface water.

A short precipitation record is of little value in planning works or development seriously affected by rainfall, because short periods are deceptive and unreliable as a basis for prediction of probable future occurrences. A 1-year record is practically of no value, a 5-year record is of little value, a 10-year record is somewhat better, a 50-year record is usually good and about the best that can be expected (42).

Binnie (10) made a complete study of the periodic variation in rainfall, and reports that a 5-year record is likely to be 15 percent in error, a record 10-years in length is 8.2 percent of the true mean, a 20-year record is 3.3 percent of the correct value and so on. Records 40 or 50 years in length, in all probability, give the mean rainfall with an average of about 2 percent, which is ordinarily near enough for all practical purposes.

Consumptive Use

The amount of water required to grow a mature crop is called consumptive use. The amount of water evaporated from surface and subsurface water to the atmosphere and used by vegetative growth in transpiration and building of plant tissue is called evapo-transpiration.

Consumptive use is an increasingly important part in irrigation science as well as in the associated political and philosophical sciences. It is one of the most important factors to be considered in planning irrigation projects, farm irrigation system layouts, and improving irrigation practices (5). In irrigation the amount and distribution of the natural precipitation is a factor affecting overall farm practice. It may influence the timing of water application, the time of seeding, and harvesting operations, and cause a build-up of salt in the soil particularly in the upper horizons of the soil profile (4).

Consumptive use should not include that portion of the total water requirement which percolates beyond the reach of plant roots, whether it be leaching requirements or unavoidable deep percolation losses (43). Crop yields are known to be highly dependent upon the ready availability of water at certain stages of growth. The knowledge of the time distribution of consumptive use is highly important in irrigation practice.

Transpiration of water by plants have been studied for the past two centuries, and likewise evaporation of water has been

studied over a long period (11). However, it was not until the first part of this century that the terms "Consumptive use" and "Evapotransipiration" came into general usage.

Many formulas have been developed in the past for determining evaporation and consumptive use of water by crops and other vegetation from meteorological data. Present methods of measuring evaporation for estimating consumptive use are in part an extention for measuring evaporation since the two are similar physical processes.

Early investigators used generally one or a combination of the following techniques (17).

1. Lysimeter tanks
2. Soil moisture depletion
3. Field plot experiments
4. Ground water fluctuations
5. Evaporation pan records
6. Integration
7. Inflow-outflow
8. Effective heat and the correlation of water use with climatological data.

All the above mentioned methods are still in use, and with recent refinements in instruments are more or less acceptable. Lysimeters tank measurements have suffered some ill repute because of the difficulty in obtaining data consistent with natural conditions. The use of lysimeters is seen to

be increasing in the Netherlands (35). Elaborate weighing equipment together with tanks have furnished apparently acceptable data. Soil moisture measurements are still important supplements to evaporation studies. Neither of the methods listed above provide a means of estimating peak requirements for a period of less than a month. Most crops have higher consumptive use rates during certain stages of growth, and for a relatively short period. A method has been developed by Jensen and Haise (26) for estimating short period crop consumptive use by using solar radiation data. The main difficulty with this method is that only limited data are available on solar radiation.

Many factors operate singly or in combination to influence the amount of water consumed by plants. Some effects involve human factors, others are related to the natural influences of the environment and to the growth characteristics of the plant. The more important of the natural influences are climate, water supply, soils and topography. The climatic factors that particularly affect consumptive use are temperature, solar radiation, precipitation, humidity, wind movement, length of the growing season and sunlight (4).

(a) Temperature. The rate of consumptive use of crops is probably affected more by temperature, which for long periods is a good measure of solar radiation, than by any

other factor. Transpiration is influenced not only by temperature but also by the area of the leaf surface, and the physiological needs of the plants, both of which are related to stage of maturity. The temperature of sunlit leaves will often be higher than air temperature whereas the temperature of shaded leaves will be several degrees lower than the air temperature. Abnormally low temperatures may produce dormancy (19)

(b) Humidity. Evaporation and transpiration are accelerated on days of low humidity and slowed during periods of high humidity. During periods of low humidity, greater rate of use of water by vegetation may be expected (11).

(c) Wind movement. With moving air evaporation of water from land and plant takes place more rapidly than under calm air conditions. Hot, dry winds and other unusual wind conditions during the growing period will affect the amount of water consumptively used. Homan (21) states that as the velocity of wind increases above approximately 2 mph, all the factors being the same, the rate of evaporation can be expected to be constant. However, under an "oasis" condition, with a hot, dry wind, the evaporation would be significantly increased by a high wind velocity.

(d) Latitude and sunlight. Although latitude may hardly be called a climatic factor, it does have considerable influence on the rate of consumptive use of water by various plants (4). Because of the earth movement and axial inclinations, the hours of daylight during the summer are much greater in the northern

latitudes than at the equator. Since sun is the source of energy used in crop growth and evaporation of water, this longer day may allow plant transpiration to continue for a longer period each day and to produce an effect similar to that of lengthening the growing season.

(e) Available water supply. All the above mentioned climatic factors influence the amount of water that potentially can be consumed in a given area. However, there are other factors that also cause differences in the consumptive use rates. Naturally, unless water is available from some source, there can be no consumptive use. If the water is cheap farmers over-irrigate and if the soil surface is frequently wet and the resulting evaporation is high, then the consumptive use may increase (4).

Thornthwaite (50) developed an exponential equation for potential or maximum evapotranspiration,

$$e = ct^a$$

Where,

e = monthly evapotranspiration, cm

t = mean monthly temperature, °C

a, c = coefficients, varying with temperature.

Blaney and Criddle (8) have developed a formula which utilizes mean monthly temperatures, amount of daylight, and a crop coefficient. This equation does attempt to take into consideration the influence of crop on evaporation. The crop

coefficient is the key factor for the determination of consumptive use. Multiplying the mean monthly temperature (t) by the possible monthly percentage of daylight hours of the year (p) gives a monthly consumptive use factor (f). Expressed mathematically,

$$u = kf \text{ and } U = \Sigma kf = KF$$

$$f = \frac{txp}{100} = \text{monthly comsumptive use factor}$$

where

t = mean monthly temperature, °F,

p = monthly percentage of daylight hours of the year,

u = monthly consumptive use, inches,

U = seasonal consumptive use, inches,

F = Sum of the monthly consumptive use factors for the period,

K = empirical consumptive-use crop coefficient for irrigation season or growing period.

There are other formulae and procedures for estimating evapotranspiration, and all of them give reliable results when applied to climatic conditions similar to those for which they were developed.

Irrigation losses.

When irrigation water is diverted from a source of supply to the farm through canals and laterals, some loss is encountered in conveyance. On the farm itself some loss is

encountered as well as the crops do not use the entire amount of water available. These losses added together then constitute the total irrigation loss from an irrigation project.

Golze (18) states that "In practice it is unfeasible to supply crop irrigation requirements without losses and waste". It is virtually impossible to operate an irrigation project without surface waste. Such wastes can also include leakage past gates, excess diversion and canal breaks.

The total irrigation loss consists of surface waste, seepage and deep percolation, evaporation and evapotranspiration from natural vegetation. These losses are encountered in conveyance to the farm and on the farm itself. Underhill (2) reports the following losses figures for southern Alberta.

Western Irrigation District	30% of diversion
Eastern Irrigation District	40% of diversion
Bow River Development	30% of diversion
St. Mary River Development	30% of diversion

The U.S. Bureau of Reclamation (61) reports that in conveyance the major part of the loss is attributed to seepage. It was reported that 37 percent of all water diverted on 46 projects in 1946, 23 percent was attributed to seepage and 14 percent to operational waste. It was stated that generally 15 to 50 percent of the water applied is lost as deep percolation. Surface farm waste averages 5 percent but ranges from 0 to 20 percent.

Irrigation project efficiency is affected by all losses of water that occur after the water is diverted. Jensen (27) states that when considering all factors influencing annual irrigation efficiency on the farm, it is not uncommon to find that runoff may average 15 percent and deep percolation 30 percent of the water delivered to the farm. In general, project irrigation efficiency varies widely from area to area. A recent study using information secured on 21 selected projects of the Bureau of Reclamation (64) in the 17 Western States of the U.S.A., indicated that the average project water conveyance efficiency for the years 1949 to 1960, was 63.0 percent, but ranged from 47.5 percent to 82.7 percent. Average farm efficiencies for those projects for the same years ranged from 32.3 to 78.2 percent with an average of 59.3 percent.

The overall use and loss from irrigation projects as reported by Davis (2) for large project areas in the Western States is as follows:

Canal losses	15 to 40% of diversion
Canal waste	5 to 30% of diversion
Delivery to farms.	30 to 70% of diversion
Surface waste.	5 to 10% of delivery
Percolation loss.	5 to 60% of delivery.

Here canal losses include all the losses such as evaporation, evapotranspiration from natural vegetation, surface waste and seepage whereas canal waste is the surface waste from canals.

The following figures were reported for the Upper Missouri Basin (2).

Net irrigation water requirement by plants. . . 13 ins.

Efficiency of farm application. 45%

Total water required at farm headgate. . . . . 29 ins

Storage and delivery efficiency. 40%

Gross diversion requirements. . . . . 73 ins

Return flow. 55%

Total irrigation loss. . . . . .40 ins

Surface waste. Surface waste is often termed as return flow. It is that portion of the items of supply (gross diversion and precipitation) which reaches the system of natural flow as surface water, and may be available for re-use (12). It is a fairly large portion of the total return flow from irrigation. It comprises the operational waste and seepage from canals, laterals and farm irrigation operations as well as runoff from precipitation on the project area. Golze (18) reports that on 25 U.S. Bureau of Reclamation projects in 15 Western States, operational losses averaged 15 percent of the water diverted.

Return flow from an irrigation project is composed of surface return flow and subsurface return flow. Surface return flow is that portion of the total return flow which returns to the source of supply as wholly surficial flow (12).

It is composed of the following,

1. Water rendered surplus in delivery and conveyance,
2. Water delivered at the farm headgate for crop use but rendered as surplus water.

Surface return flow can be measured reasonably accurately through operation of a satisfactory network of surface return flow gauging stations. The flows in these channels include the precipitation runoff, which is often negligible, and also that part of subsurface return flow which finds its way into these channels after flowing as ground water (12).

Seepage and deep percolation. Seepage represents a major source of water lost in the conveyance system. Seepage losses are dependent on the material through which the canal passes, the hydraulic properties and the physical conditions of the canal systems. It also depends on the permeability of the soil, the presence or absence of natural or artificial linings, the depth of water and its velocity and the elevation of the water table (24). Seepage of water from irrigation canals is a serious problem. Not only is the water lost, but also drainage problems are often aggravated on adjacent lands. Rohwer and Stout (41) state that the measurement of seepage losses from 400 irrigation canals, both lined and unlined, in several of the States of the U.S. arid west and in a variety of soils ranging from sandy loams to heavy clays,

the losses ranged from 17 to 67 percent of the total diversion of water. The U.S. Bureau of Reclamation (62) reports that 21 projects listed in the United States have losses from 3.8 percent in a completely lined system to 52.5 percent for a system with 5.3 miles of lined canals, the average losses being 37 percent.

Canals showing losses greater than 1.5 feet in depth per day over the wetted area should be classed as poor in water holding capacity, puddling or lining should be given consideration. Roe and Ayres (42), for unlined canals, give the following classification as a rough guide.

Poor, where losses exceed 1.5 ft in depth per day,

Fair, where losses are from 1.0 to 1.5 ft per day,

Good, where losses are from 0.5 to 1.0 ft per day,

Excellent, where losses are less than 0.5 ft per day.

They also report that seepage losses from lined canals is about one-seventh of that from unlined canals. It is of great economic importance, so economic comparisons can be made for lined and unlined canals.

Luthin (34) reports that seepage from irrigation canals in some irrigation districts may account for as much as 50 percent of the total water delivered to the project. Canal losses of 10 to 20 percent are quite common.

Records from 46 operating projects of the U.S. Bureau of Reclamation (62) shows that approximately 25 percent of the water entering unlined canals and laterals are lost as seepage before it reaches the farmers field.

Seepage loss studies in the lower Weber Canyon, Utah, show that the river losses are 4 to 5 percent of the total flow within a 1.5 mile reach just below the mouth of Weber Canyon (66).

In a study of canal seepage conducted by Teele (52), the highest canal loss was 64 percent of the water entering the ditch in a single mile of ditch. The average for large canals was approximately 1 percent per mile. Teele also states that, "A commonly accepted estimate of the loss from large unlined canals is 30 percent of the water taken at the headgate and from the measurements taken, this seems to be conservative."

Seepage from canals can be measured from inflow-outflow, ponding, seepage meter wells, laboratory tests of permeability of soils and tracing of natural and radio-active salts.

Deep percolation results from prolonged presence of excess water on an irrigated farm and persists where adequate drainage is lacking (42). This also causes a high water table.

Davis and Wilson (16) state that the passage of seepage water through the irrigated part of the farm is very slow, but the amount slowly but constantly increases. On the Cache le Poudre River Irrigation Project, about 30 percent of the water applied as irrigation was returned to the river as subsurface return flow.

In Oregon, in the Owyhee project area 61 percent of the total water diverted was lost (36). The loss consisted of

runoff and deep percolation. Deep percolation was found to be 15 percent of the water applied.

Taylor (53) states that approximately 50 percent of the farm delivery is lost on the farm, of which 32 percent was found to be deep percolation and other unmeasured losses.

A study by Israelsen and Bishop (25) of the Logan River diversion for 32 years shows that an average of 100,000 ac-ft of water was diverted to irrigate 54,000 acres of the higher lands. Not more than one-third of this was consumed, so 66,000 ac-ft flowed to the valley lands on the surface and underground causing waterlogging, salinity and alkalinity.

The damage to agricultural land due to deep percolation is caused by salt accumulation in the root zone resulting from the higher rates of evaporation induced by the nearness of the water table to the ground surface. Most of the irrigation water thus evaporated has an appreciable salt content which is left behind on evaporation (43).

Among the causes of high water tables on the farm are over-irrigation and surface waste from allowing water to run too long. There will be water logging at the upper end of the field and the lower end may not receive an ample amount of water and leaching where large amounts of water are used to remove salts from the soil. In the irrigated regions, where the soils are usually coarser and deeper, deep seepage is active so that it frequently becomes a serious factor in soil moisture conditions (42).

Measurements of deep seepage are difficult to make and can usually be accomplished with acceptable accuracy only by taking from the total available water, the sum of evaporation, consumptive use and runoff, this difference being that removed by deep seepage and percolation (24).

Evaporation and evapotranspiration from natural vegetation. The evaporation from a conveyance and farm delivery canal system is considered of a minor nature. The loss usually ranges from 1.0 to 1.5 percent of the diverted water (3, Chap. 59). In addition to this loss, appreciable quantities are lost from the free water surface and evapotranspiration from plants and natural vegetation along the canal banks and natural channels (24). The water loving natural vegetation uses from 50 to 100 percent more water than most crops. In regions of low rainfall, evaporation rates from free water surfaces are usually high. At Stevens Creek reservoir in Australia, which supplies part of the water for Broken Hills, it is reported that 3 gallons of water are evaporated for every gallon pumped (37). The loss due to evaporation from Lake Mead on the Colorado River for the period 1953 to 1960 inclusive averaged about 835,000 ac-ft (3, Chap. 40).

Undesirable phreatophytes, including salt cedar, willows and salt grass may grow profusely and spread where a high water table prevails along canals, stream and river channels, and lake borders. They consume from 1.0 to 1.75 ac-ft per acre of water annually (45). The evaporation problem is particularly acute in arid regions where phreatophytes are abound and where

water is needed. Estimates have been made that for every 10 ac-ft of water used for agricultural crops in the southern United States, 8 ac-ft are consumed by natural vegetation (45).

INVESTIGATIONAL PROCEDURE

The first step in a hydrologic budget study is to obtain and collect the necessary data for analysis. For the proposed study of the Vauxhall area of the Bow River Irrigation Project data had been collected on various items of the hydrologic budget by several agencies over a period of years. These data were made available through the courtesy of the following agencies:

1. Canada Department of Agriculture, Research Station and Substation, Lethbridge and Vauxhall, Alberta.
2. P.F.R.A., Bow River Project, Vauxhall, Alberta.
3. Canada Department of Energy, Mines and Resources, Inland Waters Branch, Calgary, Alberta (formerly Canada Department of Mines and Technical Surveys, Water Resources Branch).
4. Canada Wheat Board, Calgary, Alberta.

The Canada Department of Agricultrue provided data on precipitation for the 10-year period (1957-1966 inclusive) under investigation, and ground water data for the seven years 1960-1966 inclusive. P.F.R.A., Bow River Project provided data on the water diversion, delivery to ditch riders and farm deliveries for the 10-year period under investigation in addition to land classification information and crop acreages to 1962.

Canada Department of Energy, Mines and Resources provided data on the measured return flow for the 10-year period under investigation. The Canada Wheat Board provided the data on the crop acreages from 1962-1966 inclusive.

Description of the project area

The area of research was the Vauxhall District of the Bow River Irrigation Project. The area is centered on the town of Vauxhall and is approximately 50 miles north-east of Lethbridge (Figure 1). The area is in a flat semi-arid region of Alberta (14). The main canal stretches from Carseland, about 30 miles east of Calgary,to Ronalane. The project is divided into two blocks - Western and Central - that lie between the Bow and Oldman Rivers, which form its north and south boundaries respectively.

Water is made available by means of the Carseland Dam and diversion works on the Bow River, and about 95 miles of main canals and hundreds of miles of branch canals and laterals, ending again at the Bow River just south of Ronalane.

Of the 123,000 acres presently being irrigated, 25,000 are in the West Block which is operated by the Province of Alberta, and 93,000 acres in the Central Block operated by P.F.R.A. for the Federal Government. The Central Block has been divided into two sections, including 66,000 acres in the Vauxhall District, and 27,000 acres in the Hays District.

The Vauxhall District of the Bow River project was started early in the century by the Canada Land and Irrigation Company and has been in operation since 1920. The Federal Government acquired the project in 1950, and since then many improvements, renovations,and extentions have been undertaken.

Soils and geology

The Vauxhall District is in the semi-arid soil zone of Alberta (15). The area is covered by ground moraine. The surface portion of this moraine has been considerably altered by subsequent sorting and moving both on a micro and macro scale. The soil profiles therefore have formed in varying depths of glacial lacustrine, alluvial lacustrine, and alluvial deposited material overlaying unaltered glacial till. In most of the area the till is within 3 feet of the surface.

Two major soil groups occur, namely Chernozemic and Solonetzic. The Chernozemic group includes the Chin and Cavendish series plus the shallow phases of these. These soils have a granular A horizon containing up to three percent organic matter. The B horizon is usually prismatic, breaking fairly readily into a small to medium blocky microstructure.

The soils of this area are low in organic matter and nitrogen. The phosphorous content is limited but the potash content is comparatively high.

The types and distribution of the various surfacial deposits of the Vauxhall District are as follows (7).

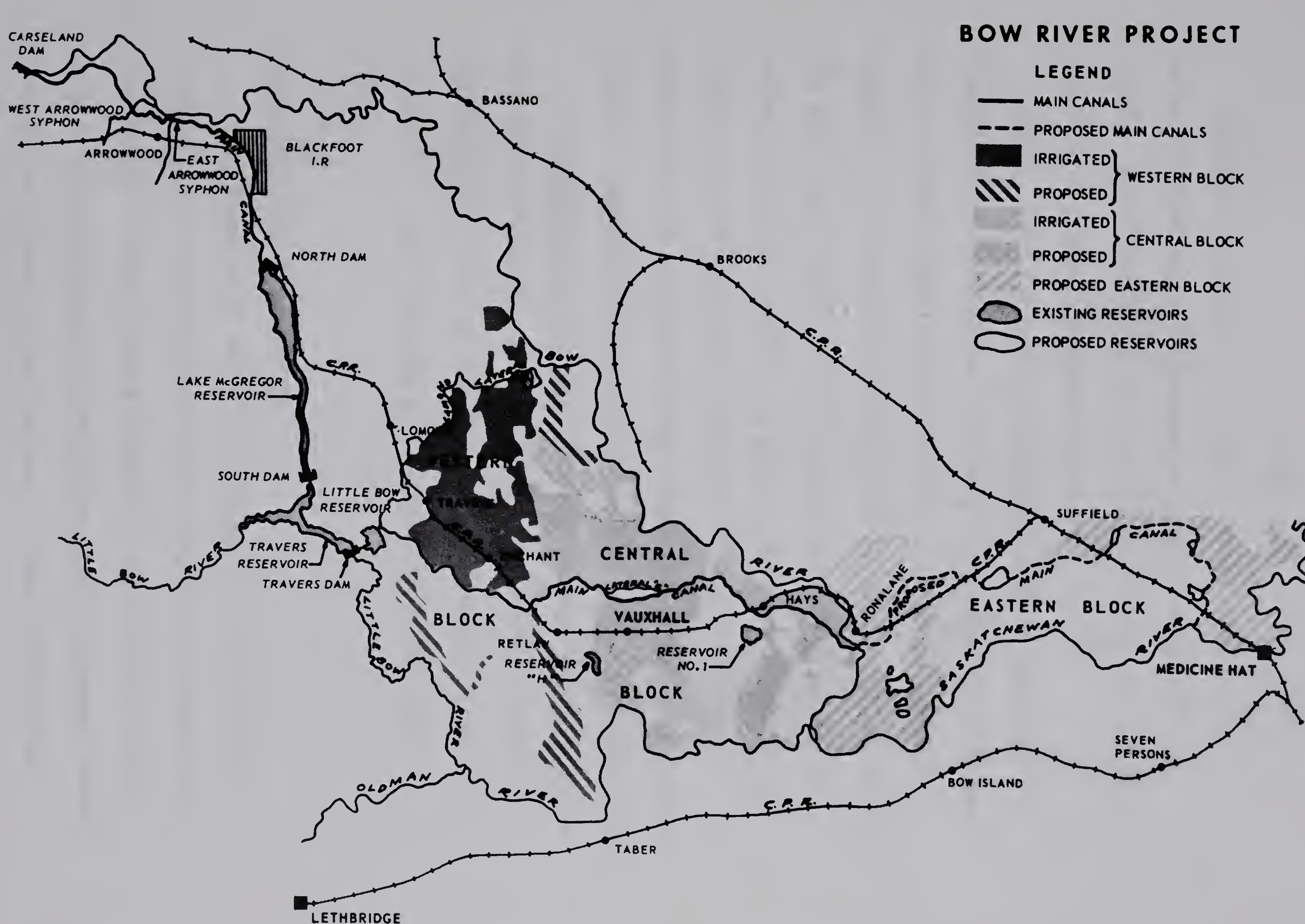


Figure 1: General Map of the Bow River Project.

Bedrock. The bedrock of the district consists of unconsolidated upper Cretaceous bentonitic sandstone and shales. Coal beds are found in places. All of the bedrock strata have a near horizontal attitude.

Till. Till consists of unsorted deposits laid down directly from the glacier. In the project area it forms most of the surface deposits and underlies most other surface deposits. It consists of equal parts of sand, silt and clay, the clay being plastic as it contains a high percentage of montmorillonite. The till is predominantly thin, generally ranging from 20 to 40 feet, and is brown in color. The gravel fraction contains a high percentage of material derived from the Canadian Shield, such as granite and metomorphic rocks.

Glacio-fluvial deposits. Glacial outwash deposits in the district are limited to a few small terrace-like deposits associated with some of the ice-walled channels. They are composed of sand, although gravel deposits are present in places.

Gross diversion and delivery

The diversion of water for irrigation to the Vauxhall District, for the purpose of this study, is considered to be the amount of water flowing through the Main Canal between Drop 7, and the Expanse Coulee Siphon, less the amount wasted through the Expanse Coulee wasteway. These locations are

shown in Figure 2. Some irrigation water is exported to the Hays District through the Expanse Coulee Siphon. Data on the water diversion, delivery to ditch riders and to farmers was made available through the courtesy of the P.F.R.A., Vauxhall. The P.F.R.A. has installed a calibrated weir at Drop 7 where the water imported to the Vauxhall District can be measured. Similarly water exported to the Hays District is measured at the Expanse Coulee Siphon. The gross diversion to the Vauxhall District was found by substracting this amount and the amount wasted through the Expanse Coulee wasteway from the amount measured at Drop 7. Water measurements were taken on a monthly basis. The data for the entire irrigation season from May to October was obtained by summation of the monthly flows. The seasonal gross diversion as well as the gross amounts delivered to ditch riders and to farmers as obtained from water master records, are shown in Table 2. The gross amount of water diverted and delivered to ditch-riders (gross delivery) and to farmers (farm delivery) in ac-ft per acre was calculated, using the actual irrigated area. The irrigation factor is the ratio of the total irrigated acreage and the total irrigable acreage of the Vauxhall District which is 53, 750 acres.

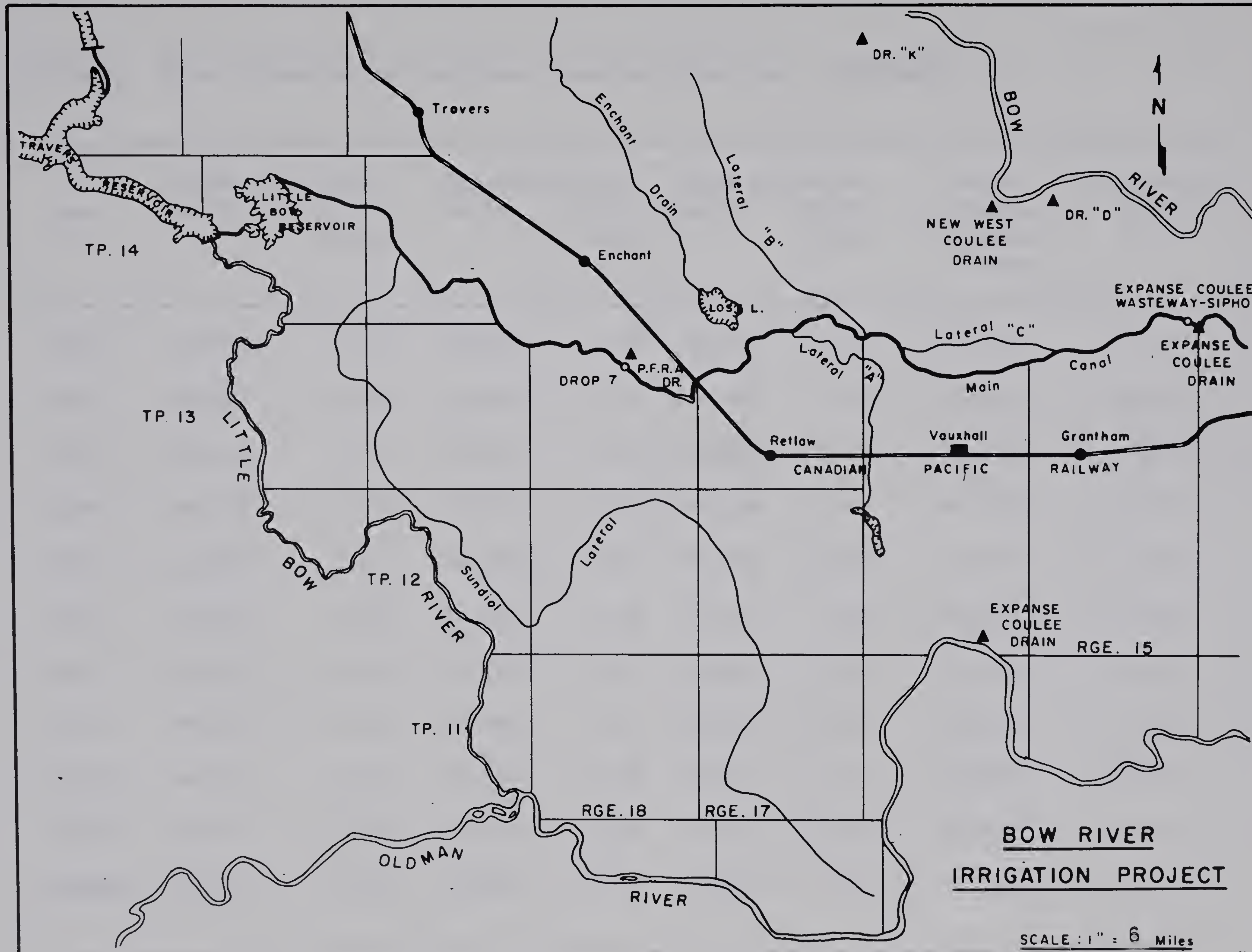


Figure 2: General Map of the Bow River Project, Vauxhall Area.

Table 2: Water diversion and delivery, Vauxhall District, 1957-1966.

Year	Gross Diversion Ac-ft	Gross Diversion Ac-ft /acre	Gross Delivery Ac-ft	Gross Delivery Ac-ft /acre	Farm Delivery Ac-ft	Farm Delivery Ac-ft /acre	Actual Irrigated Acreage, Acres	Irrigation Factor, %
1957	69,250	1.58	60,450	1.38	58,240	1.33	43,600	81.2
1958	64,030	1.41	58,660	1.29	44,500	0.98	45,310	84.3
1959	67,440	1.72	56,130	1.43	42,010	1.07	39,110	78.2
1960	86,140	1.94	76,700	1.73	62,260	1.40	44,235	82.3
1961	116,550	2.81	109,640	2.64	85,580	2.07	41,420	77.0
1962	96,980	2.05	84,430	1.79	67,140	1.42	47,110	87.0
1963	88,700	1.85	77,780	1.62	58,980	1.23	47,920	89.1
1964	97,440	1.83	91,960	1.72	70,100	1.31	53,210	99.0
1965	44,000	0.78	39,380	0.70	27,770	0.49	56,160	104.4
1966	59,160	1.09	48,170	0.89	29,640	0.54	53,930	100.3
Average	78,970	1.70	70,330	1.51	54,630	1.18	47,200	87.8

Precipitation

The long-time (1921-1950) annual precipitation for the Vauxhall District is 12.34 inches while seasonal precipitation from April to September is 8.81 inches (15). The average seasonal precipitation from 1953 to 1966 inclusive for the Vauxhall Substation was 9.94 inches while the annual precipitation for the same period was 13.20 inches. The precipitation for the enitre Vauxhall District was measured from a single rain gauge located at the Vauxhall Research Substation.

The precipitation data for the Vauxhall District covering a 10-year period (1957-1966) is presented in Table 3.

Table 3: Annual and seasonal (April-October) rainfall, Vauxhall District, 1957-1966.

Year	Apr.	May	June	July	Aug.	Sept.	Oct.	Seasonal	Annual
	Monthly precipitation, inches								
1957	.60	.31	1.68	.30	.74	1.22	1.33	6.18	8.73
1958	.68	1.06	1.75	3.02	.85	2.03	.25	9.62	13.63
1959	1.13	2.22	2.45	1.24	1.36	.90	.66	9.96	13.36
1960	2.21	1.22	.99	.79	2,03	.37	.12	7.93	11.34
1961	.11	.99	.40	2.05	1,09	1,12	1,64	7,40	9.53
1962	.37	1.36	1.39	2.32	1.10	1.51	.41	8.46	10.90
1963	.37	1.10	4.93	1.24	1.35	1.24	-	10.23	13.60
1964	2.01	2.04	1.38	1.02	.30	1.84	.06	8.85	13.65
1965	1.16	1.62	5.10	.55	2.50	2.61	.09	13.63	18.06
1966	2.38	1.24	3.27	2.64	3.48	.29	.85	14.15	18.03
Average								9.63	13.08

Land Use

The arable land of the Vauxhall District is divided into irrigable land, non-irrigable and reserved.

Irrigable land is the total acreage in the Vauxhall District that can be irrigated. Since works necessary to convey the water had been completed, all the irrigable land is actively farmed.

Non-irrigable land is that part of the project acreage which cannot be irrigated, but this does not imply that it is not farmed. Dryland farming is practiced on these non-irrigable lands. The reason that this land is classified as non-irrigable is that the topography does not permit the land to be irrigated or it may be due to saline or alkaline soils.

Reserved land is that portion of the project acreage which has been reserved for right-of-way or for future construction of schools, churches, buildings, etc.

The acreage of irrigable, non-irrigable and reserved land as taken from the classification sheets of the Vauxhall District is shown in Table 4.

Table 4: Land classification, Vauxhall District*

Land Classification	Acres	Percent of Total
Irrigable	53,750	60.8
Non-irrigable	30,490	34.5
Reserved land	4,170	4.7

* Courtesy P.F.R.A., Vauxhall, Alberta.

The crops of major importance in the Vauxhall District are wheat, oats, barley, and forage. Since 1962, specialty crops such as sugar beets, potatoes, seed peas and canning crops have been grown. Acreages of the different crops grown in the Vauxhall District from 1957-1962 were available from P.F.R.A., Vauxhall. From 1962-1966 acreage figures were obtained from the Canada Wheat Board records. Table 5 gives these acreages for the project area from 1957 to 1966 inclusive. The acreage shown under the heading of "Other" includes crops other than cereals and forages. It is implied that this is mainly the acreage in potatoes, sugar beets and specialty crops.

Table 5: Crop acreages, Vauxhall District, 1957-1966.

Year	Wheat	Oats	Barley	Rye	Fallow	Forage	Flax	Other	Non-Irrigated	Total
1957	19,340	4,795	4,405	275	18,925	5,220	6,315	3,240	5,780	68,310
1958	18,425	4,675	5,405	275	19,100	5,625	7,165	3,740	7,935	72,350
1959	16,155	4,435	4,435	215	16,945	5,325	5,235	3,310	7,695	63,755
1960	16,245	4,400	4,670	25	17,080	6,335	7,090	5,470	8,625	69,940
1961	15,740	4,075	4,830	95	17,360	6,865	3,570	6,245	9,945	68,730
1962	16,400	5,800	4,575	230	15,490	7,835	4,250	8,015	9,605	72,205
1963	17,430	2,875	6,595	1,215	16,355	8,570	4,540	6,680	6,380	70,660
1964	18,470	3,290	7,855	815	16,225	8,995	5,950	7,835	5,750	75,185
1965	19,795	2,590	10,035	545	16,690	8,940	3,970	10,260	5,300	78,140
1966	20,100	2,785	9,640	250	14,090	9,635	2,070	9,625	5,890	73,910

Consumptive Use

Recent research on the consumptive use of water on irrigated plots in southern Alberta has been reported (46) for a period of 12 years from 1949 to 1961 inclusive using irrigation, climatic and soil moisture data. The mean consumptive use figures (Table 6) as reported by Sonmor were used in estimating annual consumptive use in the hydrologic budget of the Vauxhall District. Using these crop figures this implies that a crop was never lacking ample moisture. The soil moisture deficit was replaced either by rain or irrigation water to obtain optimal yields.

Table 6: Consumptive use, southern Alberta.

Crops	Optimal consumptive use, ft
Wheat, rye	1.52
Oats, barley	1.34
Flax	1.27
Other grains	1.28
Forage crops	2.12
Potatoes	1.66
Sugar Beets	1.79
Corn	1.26
Peas	1.12
Other Vegetables	1.20
Other miscellaneous crops	1.50

The consumptive use figure for summerfallow and dryland crops are not included. It was assumed that for the summerfallow 75% of the seasonal rainfall was lost to evaporation and that 100% of the rainfall was used by the dryland crops grown on the non-irrigated acreage.

<u>Measured return flow</u>

The return flow from the Vauxhall District of the Bow River Project is composed of:

(a) Water diverted into irrigation channels for use but rendered surplus,

(b) Water salvaged as surface runoff from irrigated farm land,

(c) Part of the seepage and deep percolation from the surficial reservoirs, channels, farm land, etc.

The gauging stations for measuring the return flow are shown in Figure 2. Some estimate was made of the return flow from smaller channels which were not measured. The return flow was calculated from stage-discharge curves and hydrographs for each gauging station. The monthly return flows were summed to arrive at the total surface return flow as measured for the Vauxhall District from 1957-1966 inclusive. These are tabulated in Table 7.

Table 7: Measured surface return flow, Vauxhall District* 1957-1966.

Year	Surface return flow, ac-ft
1957	18,000[E]
1958	18,590
1959	19,220
1960	25,520
1961	31,890
1962	32,670
1963	32,990
1964	32,670
1965	26,220
1966	34,570

E Estimated on the basis of measured return flow for 1968 and 1969.

* Courtesy, Canada Department of Energy, Mines and Resources

Ground water table

The data on the fluctuation of the ground water table in the Vauxhall District from 1952 to 1966 inclusive were obtained from the Agriculture Research Station*.

These data were collected from a network of observation wells and piezometers installed in the project area. The network in the Vauxhall District consists of approximately 175 piezometers installed to a minimum 10-ft depth. The density is about 2 piezometers per section south of the Main Canal and 1 piezometer per section north of the Main Canal. These installations are read 7 or 8 times a year, 5 to 7 readings scheduled during the irrigation season. Weighted monthly water table depths and seasonal (May to October) average depths for the Vauxhall District are summarized in Table 8.

* Courtesy of Mr. E. Rapp of the Canada Department of Agriculture, Agricultural Research Station, Lethbridge, Alberta.

Table 8: Summary of seasonal ground water table fluctuations, Vauxhall District, 1960-1966

	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Seasonal average water table depth, ft
	Water table depth, ft												
1960						5.30	4.37	4.62	5.69				4.76
1961	7.10			7.30	6.73	5.99	5.47		6.40	5.92	6.13	7.13	6.04
1962				6.42	6.11	5.54	5.32	5.92	6.04	5.93	6.41		5.82
1963		6.62			5.74	5.33	5.18		5.87	5.60			5.56
1964	6.32			5.95	5.44	5.14		5.40	5.59	5.75			5.47
1965	[illegible]		4.43	4.18		4.91	5.23	5.63		5.61			5.41
1966			7.26		4.52	4.77	4.93	5.24	6.13	5.67			5.24

An annual index of water table change in terms of free water depth was determined by analysis of the difference in the yearly seasonal water table depths (Table 9). Specific yield which is defined as the volume of water that a soil after saturation will yield by gravity is estimated to be 7 percent for this study.

Table 9: Summary of annual water table index, Vauxhall District, 1960-1966.

Year	Actual water table change ft	Index, ft of free water
1960	+0.43[e]	.030
1961	+0.81[e]	.057
1962	+0.22	.015
1963	+0.26	.018
1964	+0.09	.006
1965	+0.06	.004
1966	+0.17	.012
Total	1.98	.142
Average	0.28	.020

[e] estimated

Index = Specific yield x actual water table change

RESULTS AND DISCUSSION

A hydrologic budget

A hypothetical hydrologic budget for an irrigation project is presented as a flow diagram in Figure 3. It shows the use and associated losses of diverted and delivered irrigation water.

Application of this hydrologic budget to the Vauxhall District of the Bow River Project would be as follows. The gross diverted water to the Vauxhall District between Drop 7 and the Expanse Coulee siphon (Figure 2) is delivered to ditch riders who in turn deliver the water to farmers on demand. The difference between the gross diversion and gross delivery to ditch riders is referred to as Main Canal loss. This loss can be subdivided into surface waste, seepage and deep percolation, and evaporation and evapotranspiration by natural vegetation. Based on figures from the review of literature and experience on the Bow River Project*, 75 percent of the Main Canal loss can be assumed to be surface waste, 15 percent as seepage and deep percolation and the remaining 10 percent to evaporation and evapotranspiration.

Similarly, the difference between the gross delivery to ditch riders and the farm delivery can be assumed to be the delivery losses. This loss can be broken down into various components of surface waste, seepage and deep percolation,

* Courtesy of Mr. E. Rapp, Research Branch, Lethbridge.

and evaporation and natural evapotranspiration. As the method of delivering water to farms is similar to conveyance of water in the Main Canal, the same percentages for the various losses can be used to give a reasonable estimate of each. Namely, 75 percent of the total delivery loss to surface waste, 15 percent to seepage and deep percolation and 10 percent to evaporation and evapotranspiration.

The total irrigation water delivered to the farms and the seasonal precipitation is assumed to be the total amount of water available for crop use. The seasonal precipitation (Table 3) multiplied by the total crop acreage (Table 5) gives a value from precipitation for crop use expressed in acre-feet. The runoff caused by precipitation is presumed to be a negligible amount of the total precipitation and therefore is disregarded in this study.

The consumptive use or maximum potential evapotranspiration was calculated using crop figures as reported by Sonmor (46) for southern Alberta (Table 6). To obtain the consumptive use for irrigated crops, these figures were multiplied by the respective crop acreage (Table 5). The consumptive use of fallow was assumed to be 75 percent of the seasonal rainfall multiplied by the acreage in fallow. For dryland crops, the total seasonal precipitation was assumed to be used for consumptive use. This precipitation multiplied by the area in non-irrigated or dryland crops gives a value for consumptive use by such crops, mainly cereals. The total consumptive use of irrigated crops, fallow

and dryland or non-irrigated crops is then taken as the figure for maximum potential evapotranspiration in the hydrologic flow diagrams.

The total farm losses were found by subtracting the consumptive use from the total water available for crop use. This loss is subdivided into various components of surface waste, seepage and deep percolation, and evaporation from water surfaces such as ponds and dugouts. It was estimated that 65 percent of the farm loss was surface waste, 25 percent was seepage and deep percolation and 10 percent lost to evaporation. The seepage and deep percolation loss on the farm was assumed to be higher than in conveyance of water as most of this loss on the farm would be from application of water to the land. The surface waste on the farm can be assumed to be less than in diversion and delivery of water.

The hydrologic budgets, calculated using the above assumptions and estimates, are presented for the Vauxhall District in Tables 4 to 13 for 1957 to 1966 inclusive. A summary of the hydrologic budgets, presented as items of supply and disposal, is given in Table 10. The items of supply and disposal as a percentage of the total supply of irrigation water and precipitation is given in Table 10a.

A comparison of the Vauxhall District hydrologic budget and the figures for the Upper Missouri Basin as cited from the literature (2) is made in order to compare the estimates made for

this study. For the Upper Missouri Basin,

Gross diversion	73 inches
Gross delivery.	40 inches
Farm delivery.	29 inches
Net irrigation water requirement.	13 inches
Return flow	55% of gross diversion

Therefore the total losses for the Upper Missouri Basin by subtraction are,

Canal losses.	33 inches
Conveyance losses.	11 inches
Farm delivery losses.	16 inches

As the return flow is given as 55 percent of the gross diversion, then the calculated surface return flow is 40.1 inches.

Using the suggested estimate of the losses in the Vauxhall District for surface waste, the surface return flow is as follows:

Canal losses,	75% = 24.75 inches
Conveyance,	75% = 8.25 inches
Farm delivery,	65% = 10.24 inches.

The total estimated loss to surface return flow is 43.4 inches which compares closely with the calculated figure of 40.1 inches for the Upper Missouri Basin.

It is reported (2) that 1% of the gross diversion is estimated to be evaporation loss. Thus the total evaporation loss for the Upper Missouri Basin will be 0.73 inches. On the estimate of 10% of the total losses as evaporation loss as used

for the Vauxhall District, the total evaporation loss for the Upper Missouri Basin will be 0.33 + 0.11 + 0.16 = 0.60 inches. This estimated figure is lower than the figure cited in the literature for the Upper Missouri Basin.

The remaining portion of the Main Canal, conveyance and farm delivery loss is assigned to seepage and deep percolation. For the Vauxhall District, the loss from the Main Canal in conveyance is estimated at 15% whereas on the farm it is estimated at 25 percent, the explanation being that less water is lost to seepage and deep percolation in conveyance than on the farm. On the farm the water is in a more static state of flow and therefore there is more loss due to seepage and deep percolation.

A typical example of the hydrologic budget for the Vauxhall District for one particular year, say 1960, is as follows (Figure 7).

The gross diversion to the Vauxhall District in 1960 was 86,140 ac-ft, out of which 76,700 ac-ft was delivered to the ditch riders. So 9,440 ac-ft of water was the Main Canal loss. Out of this 9,440 ac-ft, 7,080 ac-ft or 75% of the Main Canal loss was estimated to be surface waste, 1,420 ac-ft or 15% in the form of seepage and deep percolation, 940 ac-ft or 10% as loss to evaporation and consumptive use by natural vegetation.

Out of 76,700 ac-ft of water delivered to ditch riders, only 62,260 ac-ft was delivered to farmers at the farm headgate.

So a loss of 14,440 ac-ft occurred in conveyance. Out of this 14,440 ac-ft, 10,830 ac-ft or 75% of the total loss was estimated to be surface waste, 2,170 ac-ft or 15% was lost to seepage and deep percolation and 1,440 ac-ft or 10% of the total loss was evaporation and consumptive use by natural vegetation.

In addition to the 62,260 ac-ft of water delivered to farmers at the farm headgate, there was 46,160 ac-ft of seasonal precipitation in 1960. The water available on the farm was then 108,420 ac-ft. Out of this 108,420 ac-ft, 80,430 ac-ft was calculated as the optimal water requirement of crops in the Vauxhall District in 1960. The crop acreage for wheat and rye, oats and barley, forage crops, flax and other crops mainly specialty crops, for 1960 was 16,270, 9,070, 6,335, 7,090 and 5,470 acres respectively (Table 5) for a total irrigated acreage of 44,235 acres. The average optimal consumptive use for wheat and rye is 1.52 ft, oats and barley is 1.34, forages is 2.12, flax is 1.27, and other grain crops is 1.28 (Table 6). These are considered to be the irrigated crops, but in addition to these there are dryland crops and summerfallow, which are not considered to be irrigated. Dryland is assumed to consume 100 percent of the seasonal rain and the summerfallow 75 percent. The dryland or non-irrigated crops for the year 1960 was 8,620 acres, and the seasonal rainfall was 0.66 ft, so the total water used by dryland crops was 5,690 ac-ft. Summerfallow was 17,080 acres and the 75 percent of the seasonal rainfall was 0.49 ft, so summerfallow used 8,370 ac-ft of water.

The addition of all these figures gave the total water requirement of 80,430 ac-ft which could be used by crops grown in Vauxhall District for their optimal growth.

The difference between the water available for crop use and the total consumptive use is 27,990 ac-ft which is considered to be irrigation farm loss. This loss consists of 18,190 ac-ft or 65% of the total farm loss as surface waste flowing back through the natural channels as surface return flow, 7000 ac-ft or 25% as seepage and deep percolation loss and 2,800 ac-ft or 10% as evaporation loss.

So, adding the gross diversion to the precipitation, the total items of supply for the year 1960 was 132,300 ac-ft.

The items of disposal consisted of 80,430 ac-ft of water that could be used consumptively by crops, 36,100 ac-ft of surface waste flowing back to natural channels as surface return flow, 10,590 ac-ft lost to seepage and deep percolation and 5,180 ac-ft being evaporation from free water surfaces, farm dugouts and reservoirs, and water consumed by natural vegetation. Therefore the items of disposal for the year 1960 was 132,300 ac-ft, which equals the items of supply.

Figure 3: Flow Diagram of the hydrologic budget.

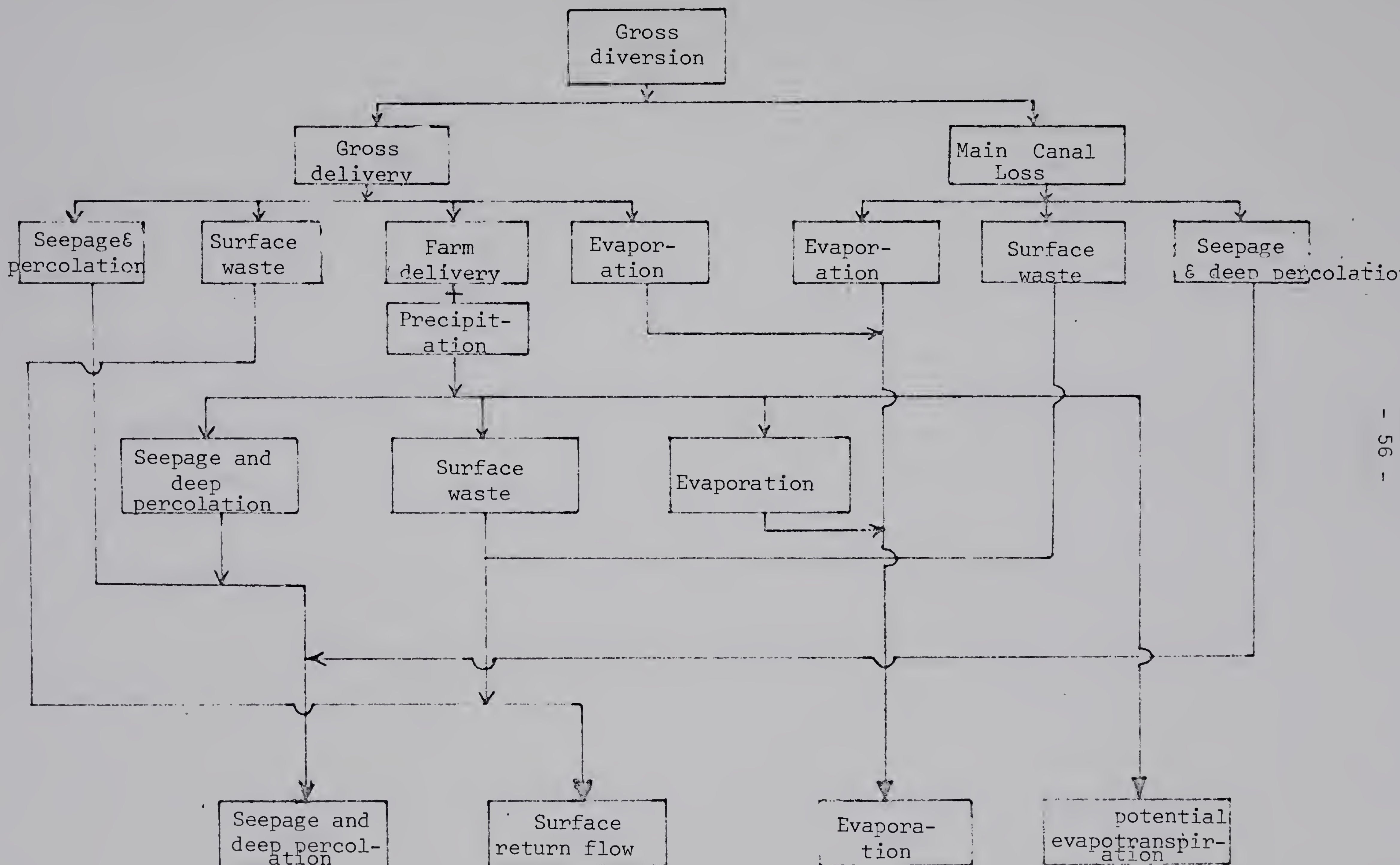


Figure 4: Hydrologic budget for the Vauxhall District, 1957.

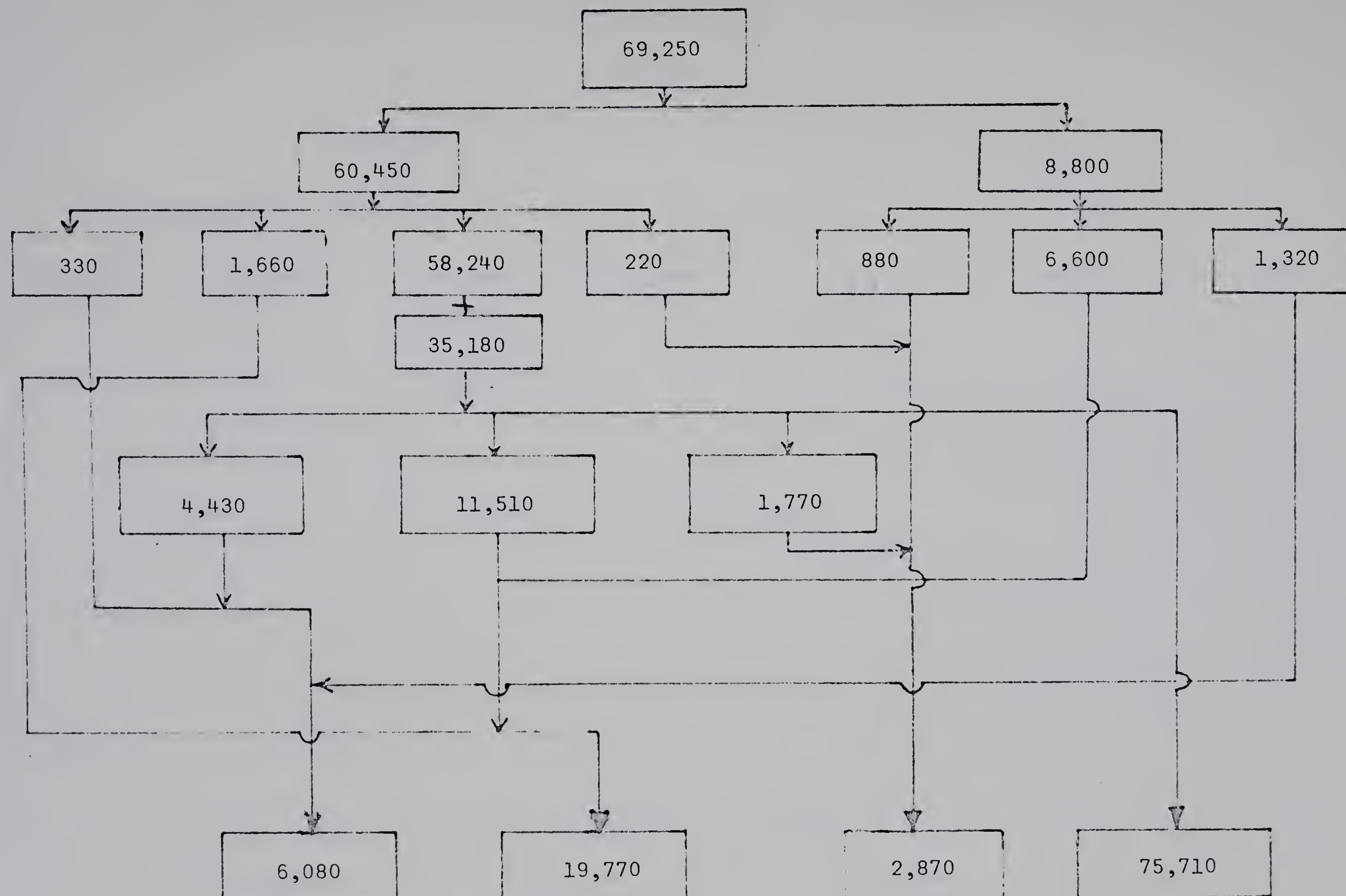


Figure 5: Hydrologic budget for the Vauxhall District, 1958

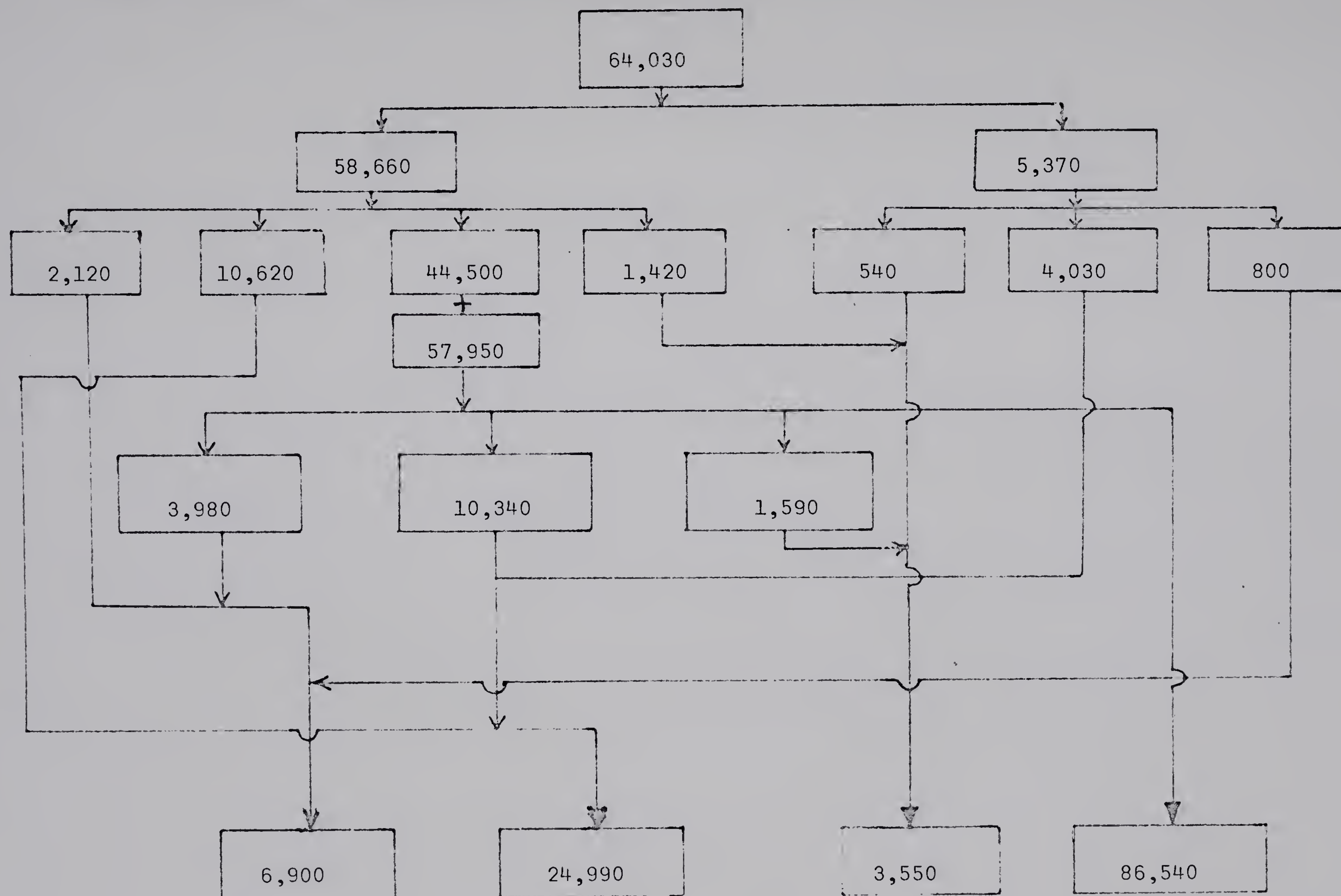


Figure 6: Hydrologic budget for the Vauxhall District, 1959

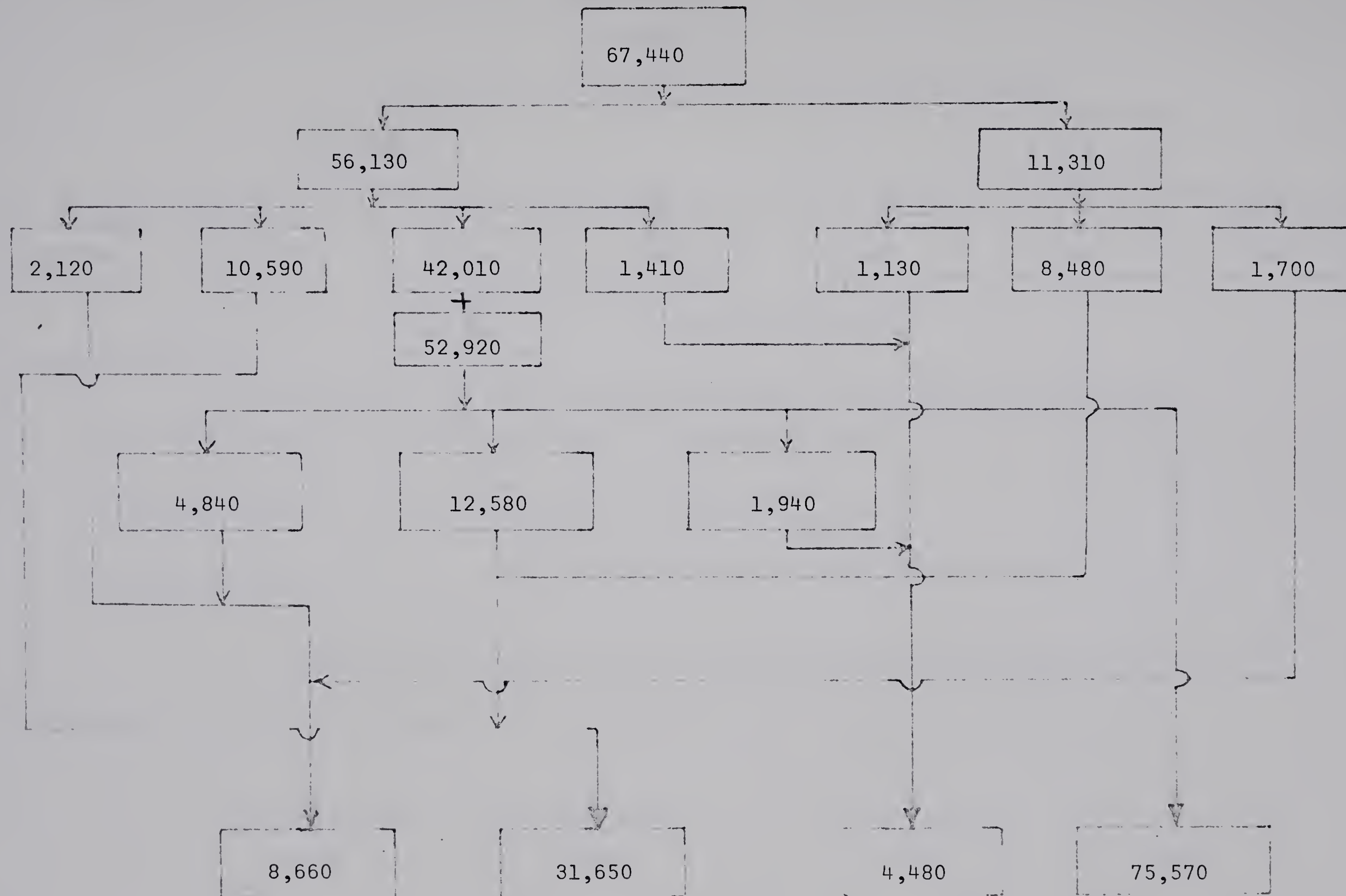


Figure 7: Hydrologic budget for the Vauxhall District, 1960.

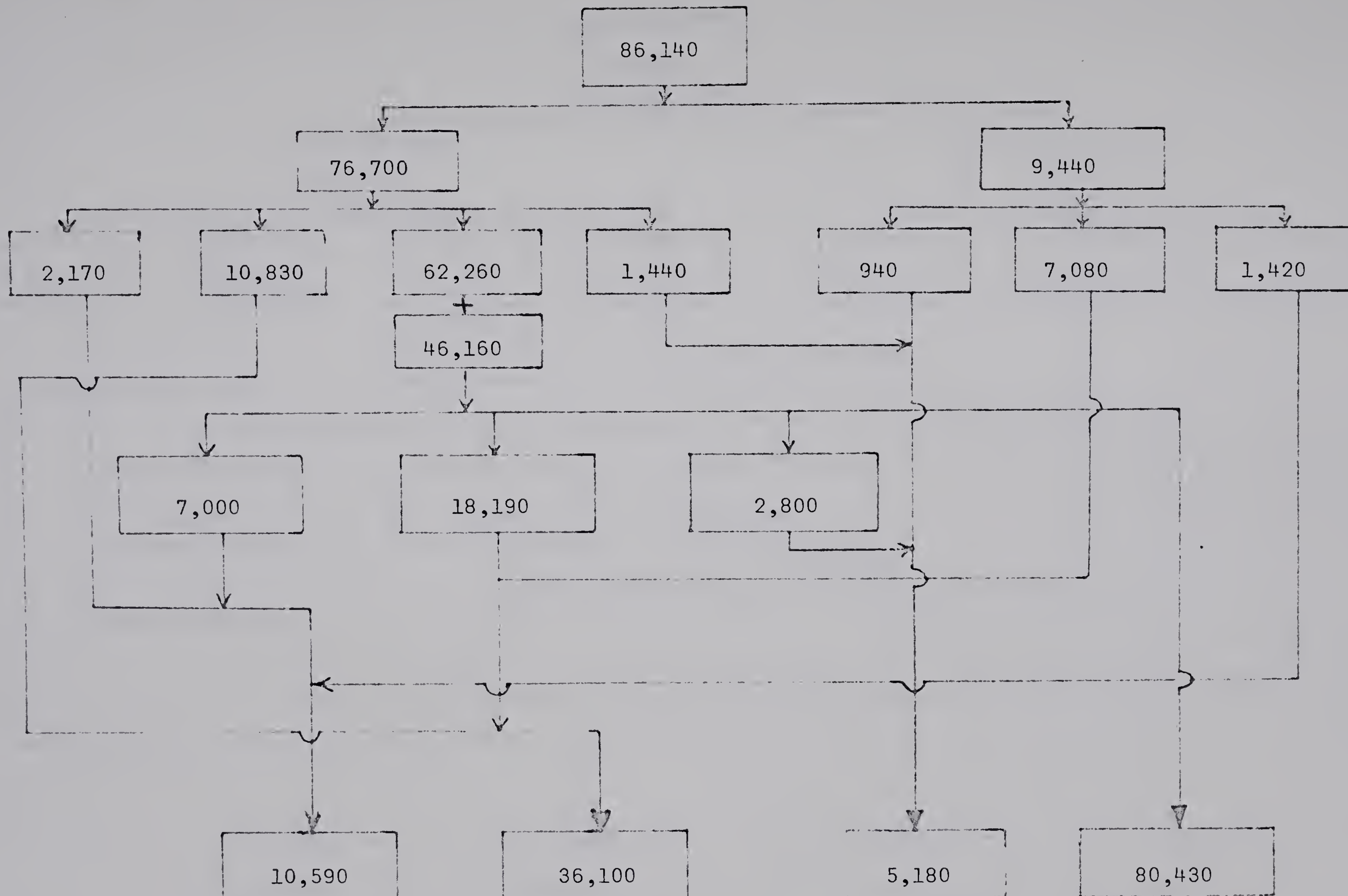


Figure 8: Hydrologic budget for the Vauxhall District, 1961.

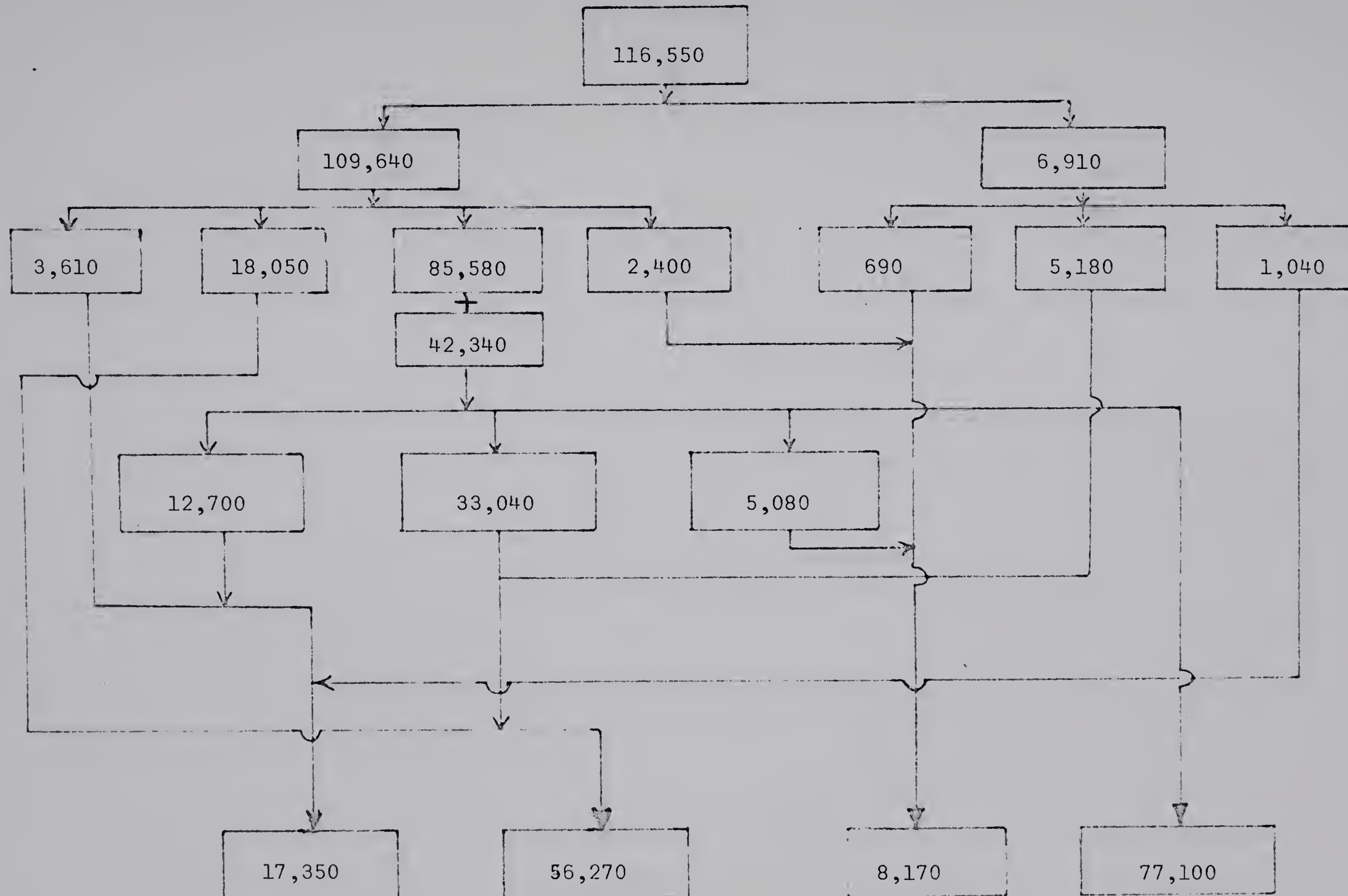


Figure 9: Hydrologic budget for the Vauxhall District, 1962

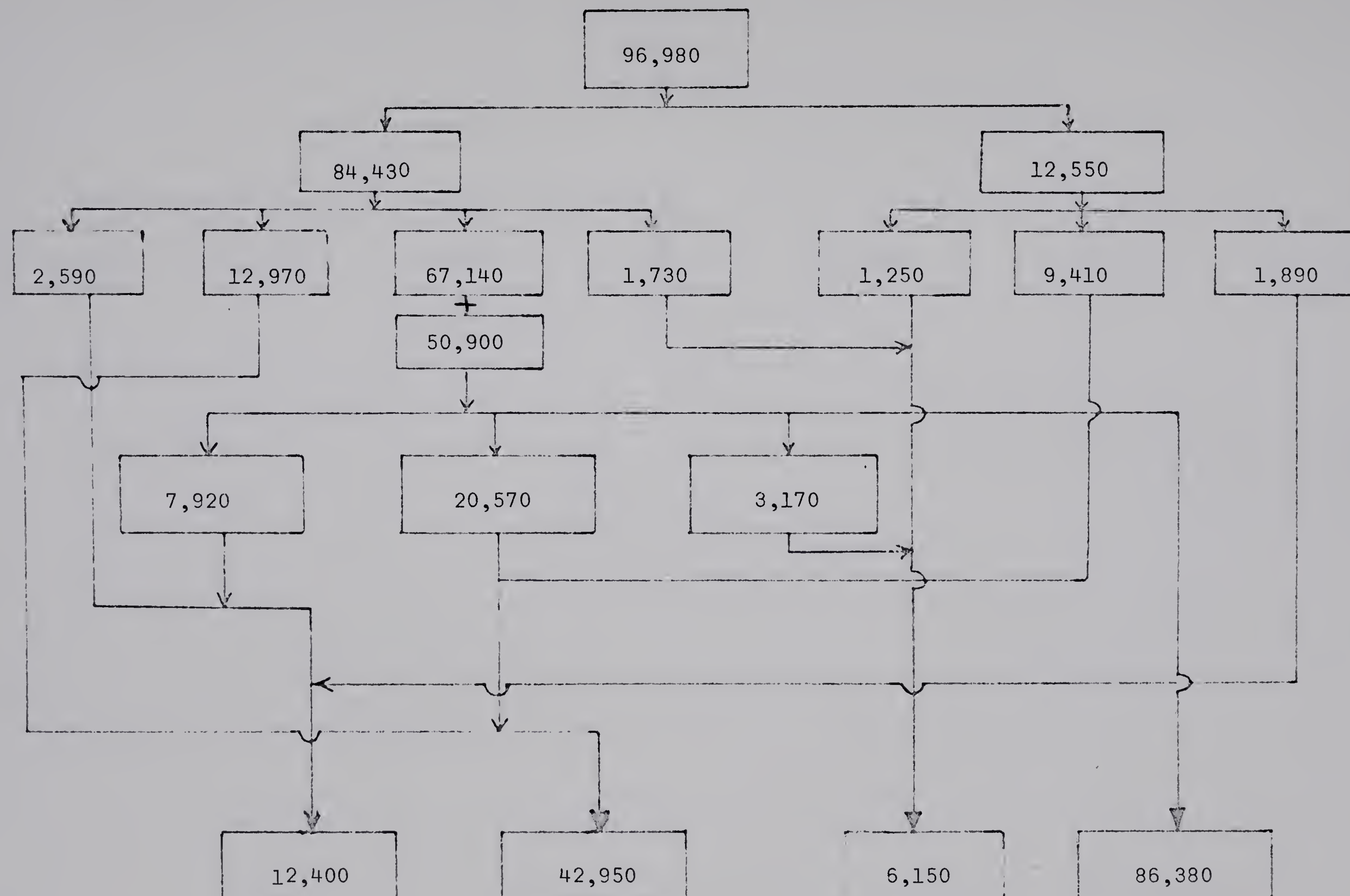


Figure 10: Hydrologic budget for the Vauxhall District, 1963.

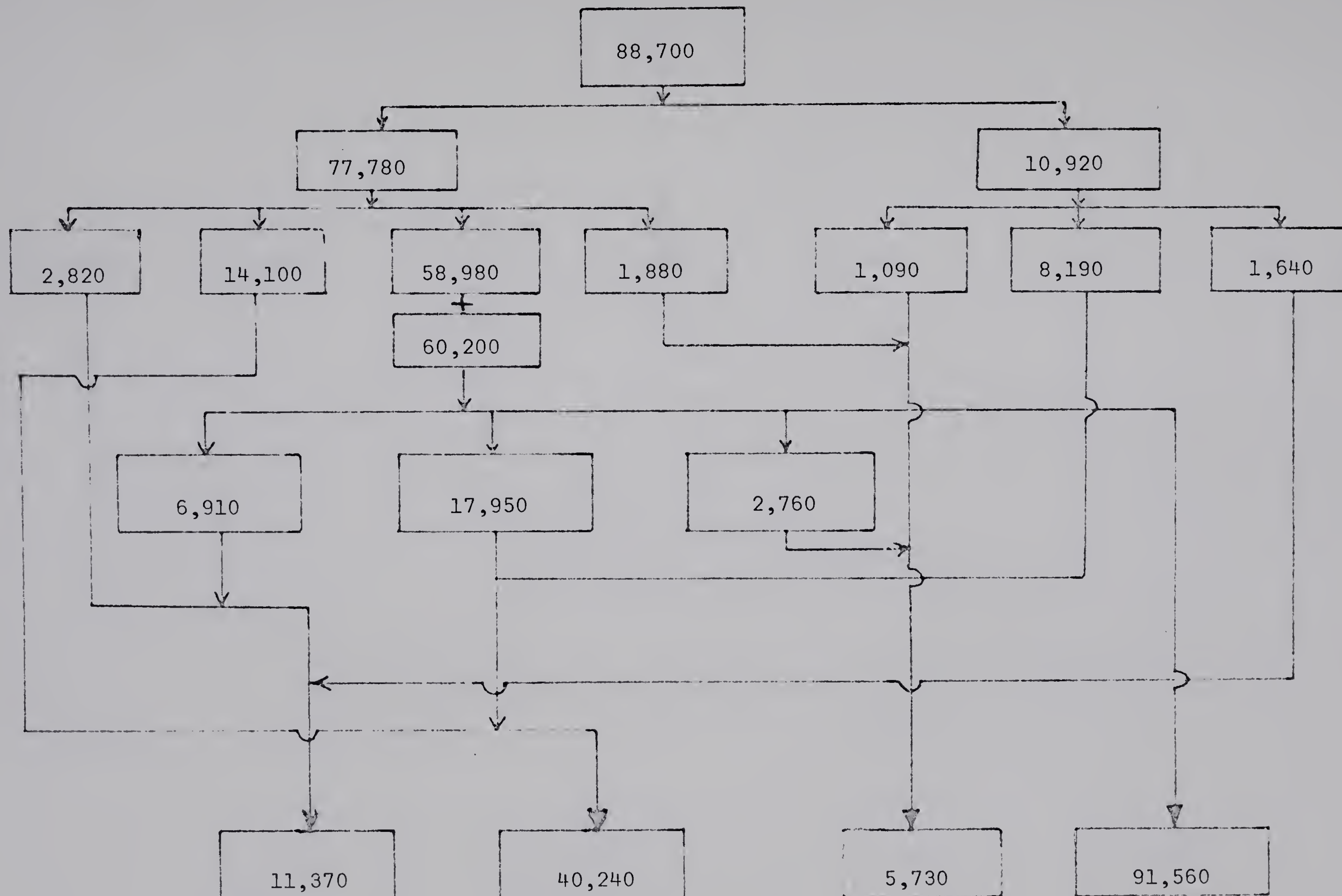


Figure 11: Hydrologic budget for the Vauxhall District, 1964.

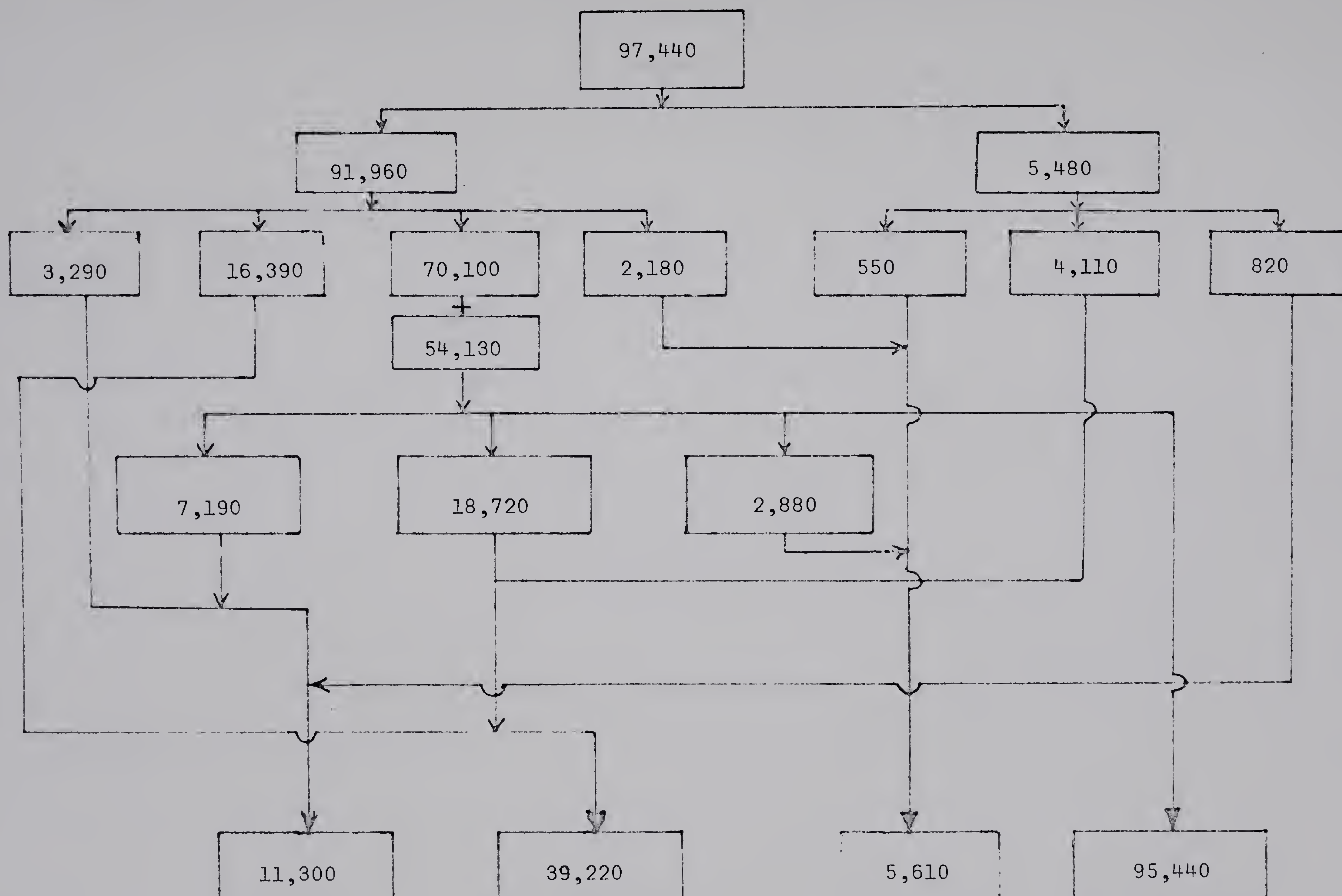


Figure 12: Hydrologic budget for the Vauxhall District, 1965.

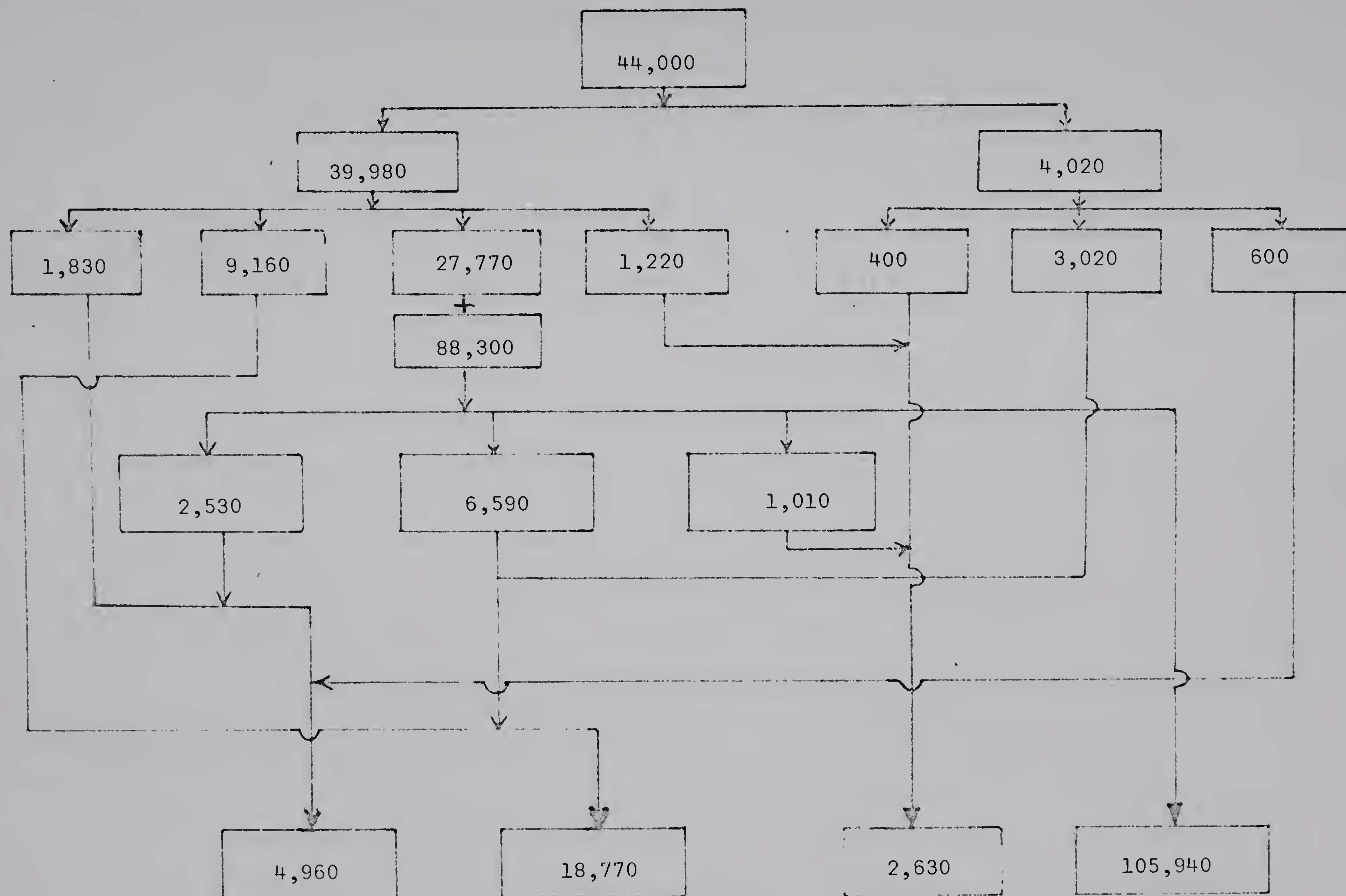


Figure 13: Hydrologic budget for the Vauxhall District, 1966.

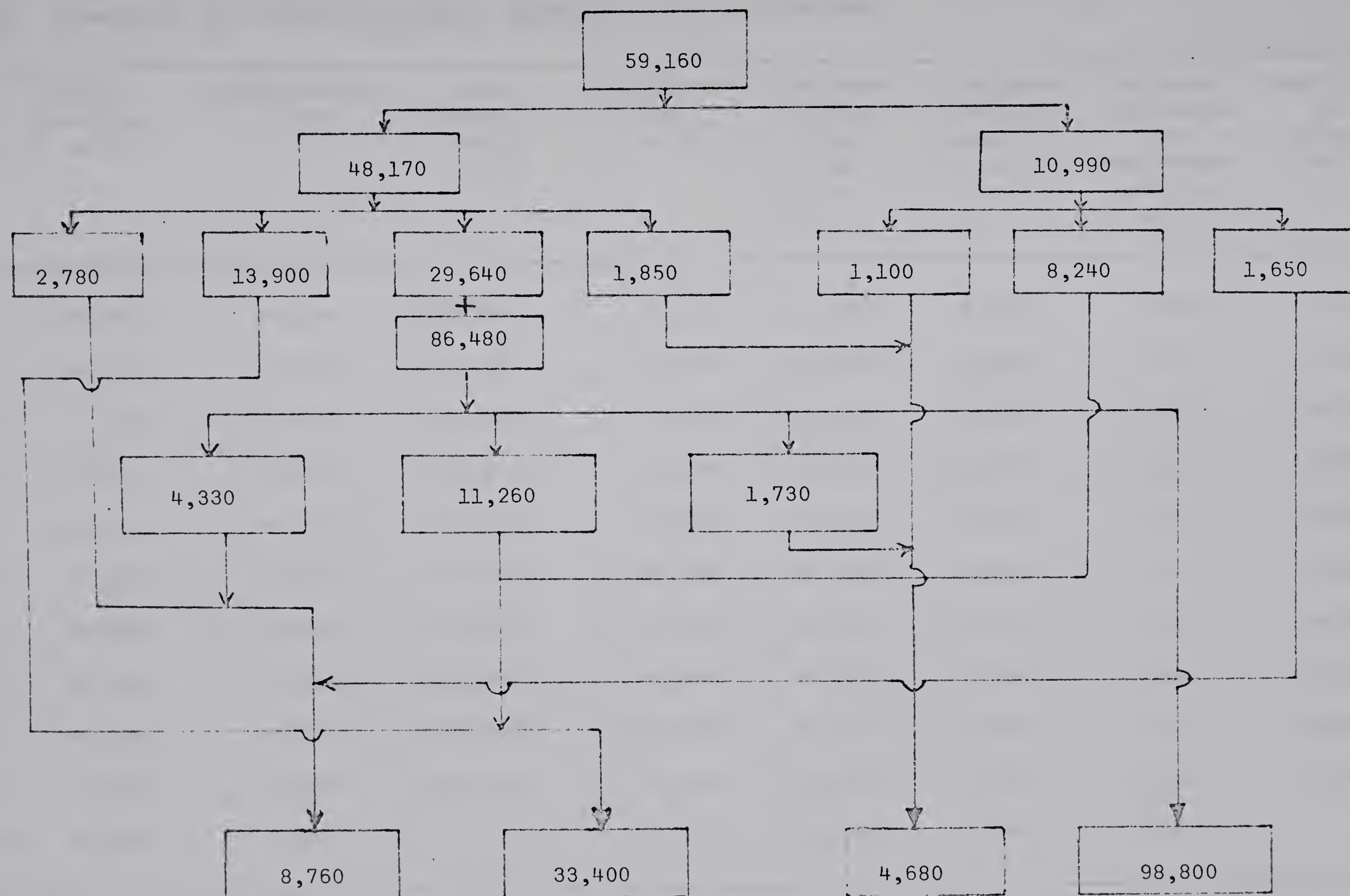


Table 10: Summary of the hydrologic budget, Vauxhall District, 1957-1966.

Year	Gross diversion, ac-ft	Precipitation, ac-ft	Total items of supply, ac-ft	Consumptive use, ac-ft	Estimated surface return flow, ac-ft	Estimated seepage & deep percolation, ac-ft	Estimated evaporation and evapotranspiration, ac-ft	Total items of disposal, ac-ft
1957	69,250	35,180	104,430	75,710	19,770	6,080	2,870	104,430
1958	64,030	57,950	121,980	86,540	24,990	6,900	3,550	121,980
1959	67,440	52,920	120,360	75,570	31,650	8,660	4,480	120,360
1960	86,140	46,160	132,300	80,430	36,100	10,590	5,180	132,300
1961	116,550	42,340	158,890	77,100	56,270	17,350	8,170	158,890
1962	96,980	50,900	147,880	86,380	42,950	12,400	6,150	147,880
1963	88,700	60,200	148,900	91,560	40,240	11,370	5,730	148,900
1964	97,440	54,130	151,570	95,440	39,220	11,300	5,610	151,570
1965	44,000	88,300	132,300	105,940	18,770	4,960	2,630	132,300
1966	59,160	86,480	145,640	98,800	33,400	8,760	4,680	145,640
Average	78,970	57,460		87,350	34,340	9,840	4,910	

Table 10a: Items of supply and disposal as a percentage of the total supply Vauxhall District, 1957-1966.

Year	Gross diversion, %	Precipitation, %	Consumptive use, %	Estimated surface return flow, %	Estimated seepage and deep percolation, %	Estimated evaporation and evapotranspiration,%
1957	66	34	72.6	18.9	5.8	2.7
1958	53	47	71.0	20.5	5.6	2.9
1959	56	44	63.1	26.0	7.2	3.7
1960	65	35	60.8	27.3	8.0	3.9
1961	74	26	48.5	35.5	10.9	5.1
1962	66	34	58.4	29.1	8.4	4.1
1963	60	40	61.8	26.8	7.6	3.8
1964	65	35	63.0	25.9	7.4	3.7
1965	34	66	80.1	14.2	3.7	2.0
1966	41	59	67.8	23.0	6.0	3.2
Average	58.0	42.0	64.7	24.7	7.1	3.5

Items of supply

Gross diversion

The gross diversion to the Vauxhall District of the Bow River Project ranges from 0.78 to 2.81 ac-ft/acre, the gross delivery from 0.70 to 2.64 ac-ft/acre and the farm delivery from 0.49 to 2.07 ac-ft/acre (Table 2). As an example, for 1961, it can be seen that the diversion was 2.81 ac-ft/acre, out of which only 2.64 ac-ft/acre reached the delivery canals which means a loss of 0.17 ac-ft/acre in delivery and 2.07 ac-ft/acre reached the farm headgate. So 0.74 ac-ft/acre was lost in conveyance from the main canal to the farm headgate. It seems that diversion is highest when the precipitation is low as in 1961. Gross diversion as a percentage of items of supply ranges from 34 to 74 percent (Table 10a). The lowest figure was for the year 1965, when the seasonal precipitation within the area was 4 inches above the average, and the amount of water diverted was lowest for the 10-year period under study. On the average, gross diversion is found to be 58.0 percent of the items of supply.

From statistical calculations, gross delivery and farm delivery, on the average for the 10-year period, was found to be 88.6$\pm$ 3.8 and 68.2$\pm$ 6.3 percent respectively of the gross diversion. In other words, 31.8 percent of the water diverted to the Vauxhall District was lost before it reached the farms.

Precipitation

The annual precipitation in the Vauxhall District varied from 8.73 to 18.06 inches (Table 3) while the seasonal (April-October) precipitation ranged from 6.18 inches to 14.15 inches. The average annual and seasonal precipitation for the 10-year period was 13.08 and 9.63 inches respectively.

Precipitation, on the average, as a percentage of the items of supply ranges from 34 to 66 percent (Table 10a), while the 10-year average was found to be 42 percent indicating the varying need for irrigation in the Vauxhall District. It appears that when the precipitation is below normal, the gross diversion is highest. The precipitation supply for the year 1961 was below average, being 42,340 ac-ft, while the average is 57,460 ac-ft (Table 10). Thus during the driest year the water diversion was highest being 116,550 ac-ft. Correlation analysis also show this trend. The relationship of precipitation vs gross diversion (Figure 14) shows a negative slope. The higher the rainfall the lower the diversion. If the graph is extended to exceed a seasonal rainfall of 15×10^4 ac-ft, there would practically be no diversion of water. This amounts to a rainfall of approximately 25.2 inches.

Items of disposal

Consumptive use

The water that could be used consumptively by crops in the Vauxhall District of the Bow River Project varied from 75,710 ac-ft in 1957 to 105,940 ac-ft in 1965 (Table 11). The crop acreage ranged from 63,755 acres in 1959 to 78,140 acres in 1965. Most of the grain crops grown in the area cover about the same acreage for the years under investigation. The specialty crops which includes potatoes, sugar beets, mustard and canning peas have been increasing year by year. Table 6 shows that the specialty crops grown (under the heading of other crops) require 1.12 to 1.79 ft of water. For 1957 the consumptive use was 75,710 ac-ft. The specialty crop acreage was 3,240 acres of the total acreage of 68,310 acres. The average amount of water consumed by crops for that particular year was 1.11 ft/acre. For the year 1965, the total crop acreage was 78,140 acres with the specialty crops totalling 10,260 acres. The water requirement for that year was 1.35 ac-ft. It appears that the more specialty crops grown, the higher the total consumptive use.

Consumptive use as a percentage of the items of supply is found to vary from 48.5 percent for 1961 when the diversion was highest to 80.1 percent in 1965 when the diversion was lowest and the seasonal precipitation was highest. The reason for this higher consumptive use figure

is that the crop acreage was also highest being 78,140 acres and the specialty crops acreage was also highest being 10,260 acres. Another factor to be considered is that 75 and 100% of the seasonal precipitation was considered to be used by summer-fallow and dryland crops respectively, more water use is calculated in wet years than in dry years. Thus the water consumption was highest for the year 1965 increasing the average consumptive use as a percentage of items of supply for the 10-year study period. On the average, consumptive use as a percentage of items of supply for the 10-year study period was found to be 64.7 ± 4.9 percent.

Table 11: Summary of items of supply and consumptive use, Vauxhall District, 1957-1966.

Year	Items of supply, ac-ft	Crop acreage, acres	Consumptive use, ac-ft	Average Consumptive use, ft/ac	Consumptive use/ items of supply,%
1957	104,430	68,310	75,710	1.11	72.5
1958	121,980	72,350	86,540	1.19	71.0
1959	120,360	63,755	75,570	1.19	63.1
1960	132,300	69,940	80,430	1.15	60.8
1961	158,890	68,730	77,100	1.12	48.5
1962	147,880	72,205	86,380	1.19	58.4
1963	148,900	70,660	91,560	1.30	61.5
1964	151,570	75,185	95,440	1.27	63.0
1965	132,300	78,140	105,940	1.35	80.1
1966	145,640	73,910	98,800	1.33	67.8
Average	136,430	71,320	87,350	1.22	64.7

Total irrigation losses

Irrigation losses in the Vauxhall District are the sum total of surface, subsurface and evaporation losses in diversion from the Main Canal, in conveyance to the farm headgate and from the farm use of water. The total irrigation losses as estimated varied from 26,360 ac-ft for 1965 to 81,790 ac-ft for 1961 (Table 12). It is seen that the lower the diversion of water, the lower are the total irrigation losses and vice versa. The highest losses of 81,790 ac-ft was in 1961 when the diversion was 116,550 ac-ft, whereas the lowest figure was for 1965 when the diversion was only 44,000 ac-ft.

Total irrigation losses as a percentage of the items of supply was found to vary from 19.9 to 51.4 percent (Table 12). On the average, for the 10-year study period under investigation, the irrigation losses are found to be 35.3±6.2 percent of the items of supply (Table 12).

Table 12: Summary of items of supply and total irrigation loss, Vauxhall District, 1957-1966.

Year	Items of supply, ac-ft	Total irrigation losses, ac-ft	Total irrigation losses /items of supply, %
1957	104,430	28,720	27.5
1958	121,980	35,440	29.5
1959	120,360	44,790	37.1
1960	132,300	51,870	39.1
1961	158,890	81,790	51.4
1962	147,880	61,500	41.5
1963	148,900	57,340	38.5
1964	151,570	56,130	37.0
1965	132,300	26,360	19.9
1966	145,640	46,760	32.1
Average	136,430	49,070	35.3

Surface Return Flow. The addition of the conveyance surface waste, delivery surface waste and the farm delivery surface waste gives the total estimated surface return flow for the Vauxhall District. The components and the total surface return flow is shown in Table 13. Conveyance surface waste in comparison to delivery and farm surface waste is low, ranging from 3,020 ac-ft for 1965 to 9,410 ac-ft for 1962. This may be due to the fact that the conveyance canals were maintained properly. The delivery surface waste ranges from 1,660 ac-ft to 18,050 ac-ft, and the farm surface waste from 11,260 ac-ft to 33,040 ac-ft. The highest figures for both of these surface wastes was for the year 1961 when the diversion was highest. It indicates that when more water was diverted, higher losses were incurred. The total estimated surface waste was found to vary from 18,770 ac-ft for 1965 when the precipitation was above normal to 56,270 ac-ft when the precipitation was low. On the average, for the 10-year investigational study the total estimated return flow was found to be 34,380 ac-ft.

The estimated return flow when compared with the measured return flow is found to be approximately 7,000 ac-ft higher, on the average (Table 14).

The measured return flow varied from 18,590 ac-ft for the year 1959 to 34,570 ac-ft for the year 1966 (Table 14). An increase in return flow coincides with an increase in gross diversion. For 1965 when the diversion was lowest, the measured return flow dropped from 32,670 ac-ft to 26,220 ac-ft. Again

for the year 1966 when the diversion was higher, the measured return flow increased from 26,220 to 34,570 ac-ft.

On the average, measured return flow as a percentage of the total items of supply was 19.7 percent ranging from 15.2 percent to 23.7 percent. Measured return flow as percentage of total estimated irrigation loss ranged from 39.0 to 99.4 percent. This higher figure indicates that almost the whole of the irrigation loss flowed back as surface return flow, which is unbelieveable. It could be that some of the subsurface return flow from the previous years flowed back as surface flow for that particular year. The measured return flow on the average is found to be 59.0±12.9 percent of the total estimated irrigation losses.

Measured return flow as percentage of the estimated return flow varied from 56.7 percent for 1961 to 139.6 percent for 1965. The latter high figure shows that for 1965 the estimate of the surface return flow was low or the actual measurement of the surface return flow reflects a higher runoff from precipitation. On the average it was found that the estimated return flow is 16 percent higher than the measured return flow during the 10-year study period.

Table 13: Components of estimated surface return flow, Vauxhall District, 1957-1966

Year	Conveyance surface waste, ac-ft	Delivery surface waste, ac-ft	Farm delivery surface waste, ac-ft	Total estimated surface waste, ac-ft
1957	6,600	1,660	11,510	19,770
1958	4,030	10,620	10,340	24,990
1959	8,480	10,590	12,580	31,650
1960	7,080	10,830	18,190	36,100
1961	5,180	18,050	33,040	56,270
1962	9,410	12,970	20,570	42,950
1963	8,190	14,100	17,950	40,240
1964	4,110	16,390	18,720	39,220
1965	3,020	9,160	6,590	18,770
1966	8,240	13,900	11,260	33,400
Average	6,445	11,380	16,070	34,380

Table 14: Comparison of estimated and measured return flow, Vauxhall District, 1957-1966.

Year	Total irrigation loss, ac-ft	Estimated surface return flow, ac-ft	Measured surface return flow, ac-ft	Measured return flow/total irrigation loss, %	Measured return flow/estimated return flow,%	Measured return flow/ items of supply,%
1957	28,720	19,770	18,000[e]	62.6	91.4	17.2
1958	35,440	24,990	18,590	52.4	74.3	15.2
1959	44,790	31,650	19,220	43.0	60.7	15.5
1960	51,870	36,100	25,520	49.2	70.5	19.3
1961	81,790	56,270	31,890	39.0	56.7	20.0
1962	61,500	42,950	32,670	53.1	76.3	22.1
1963	57,340	40,240	32,990	57.5	82.0	22.2
1964	56,130	39,220	32,670	58.2	83.3	21.6
1965	26,360	18,770	26,220	99.4	139.6	19.8
1966	46,760	33,400	34,570	74.0	103.5	23.7
Average	49,070	34,380	27,230	59.0	84.0	19.7

Seepage and deep percolation. The addition of all the seepage and deep percolation losses from the Main Canal, delivery and on the farm gives the total figure for the estimated seepage and deep percolation losses for the Vauxhall District (Table 15). The conveyance seepage loss ranges from 600 ac-ft for 1965 to 1890 ac-ft for 1962. When diversion is low the estimated seepage and deep percolation loss will also be low. On the average, seepage loss from the Main Canal conveyance system is found to be 1,290 ac-ft for the 10-year study. The delivery system seepage and deep percolation loss is approximately constant ranging from 1,830 to 3,610 ac-ft, except for 1957. On the average, the seepage and deep percolation loss from the delivery system is found to be 2,380 ac-ft, just about double the figure from the conveyance system. Farm seepage and deep percolation loss for all the years under study is found to be the highest, ranging from 2,530 ac-ft to 12,700 ac-ft. This farm seepage and deep percolation loss is highest due to the fact that more water is available for use on the farm. On the average, the seepage and deep percolation loss is found to be 6,180 ac-ft on the farm.

The estimated total seepage and deep percolation from the Vauxhall District ranged from 4,960 ac-ft for 1965 to 17,350 ac-ft for 1961. On the average, it is found to be 9,850 ac-ft. Seepage and deep percolation loss as a percentage of the items of supply ranged from 3.8 to 10.9 percent, the

average for the 10-year period being 71 ± 2.4 percent.

An estimate was made, using the average calculated seepage and deep percolation loss from the Vauxhall District, of the average flow to the rivers by using the annual water table index (Table 9). The method of calculation used is similar to that used by Sadler (44). The average estimated seepage and deep percolation loss for the 7-year period, 1960 to 1966 inclusive, is 10,960 ac-ft. The average seasonal (May-October) contribution to the water table can be found by multiplication of the water table index and the total area covered by the piezometer network which is approximately 85,000 acres. This would then be 0.020 x 85,000 or 1,750 ac-ft of free water recharge to the water table during a season. The seasonal flow to the rivers or natural channels can be considered as the difference between the total seepage and deep percolation loss and the recharge to the water table or 9,210 ac-ft. This residual represents a flow of approximately 31 cfs for the 150-day season or approximately 13cfs as an annual base flow. In summary, the average seepage and deep percolation losses represent 0.13 ft of free water while the actual water table recharge or index represents on the average, 0.02 ft of free water and the residual 0.11 ft of free water. The actual recharge to the water table is 15 percent of the average seepage and deep percolation losses on the project.

Table 15: Components of total seepage and deep percolation losses, Vauxhall District, 1957-1966.

Year	Conveyance seepage and deep percolation loss, ac-ft	Delivery seepage and deep percolation loss, ac-ft	Farm seepage and deep percolation loss, ac-ft	Total seepage and deep percolation loss, ac-ft	Seepage and deep percolation/items of supply,%
1957	1,320	330	4,430	6,080	5.8
1958	800	2,120	3,980	6,900	5.6
1959	1,700	2,120	4,840	8,660	7.2
1960	1,420	2,170	7,000	10,590	8.0
1961	1,040	3,610	12,700	17,350	10.9
1962	1,890	2,590	7,920	12,400	8.4
1963	1,640	2,820	6,910	11,370	7.6
1964	820	3,290	7,190	11,300	7.4
1965	600	1,830	2,530	4,960	3.8
1966	1,650	2,780	4,330	8,760	6.0
Average	1,290	2,370	6,180	9,840	7.1

Evaporation losses. The evaporation loss from the Main Canal conveyance system of the Vauxhall District ranged from 400 ac-ft to 1,250 ac-ft, the average being 860 ac-ft for the 10-year period under investigation (Table 16). Generally, it is almost constant. The delivery evaporation loss ranged from 220 ac-ft to 2,440 ac-ft. This too is almost constant for the 10 years, the average figure being 1,580 ac-ft. The evaporation loss on the farm itself varied from 1,010 ac-ft to 5,080 ac-ft. The total evaporation losses for the Vauxhall District of the Bow River Project varied from 2,630 ac-ft to 8,170 ac-ft, the average being 4,900 ac-ft. Evaporation as a percentage of the items of supply ranged from 2.0 to 5.1 percent, the average for the 10-year period under study being 3.5±0.04 percent.

Table 16: Components of total evaporation losses, Vauxhall District, 1957-1966

Year	Conveyance evaporation loss, ac-ft	Delivery evaporation loss, ac-ft	Farm evaporation loss, ac-ft	Total evaporation loss, ac-ft	Evaporation loss/items of supply,%
1957	880	220	1,770	2,870	2.7
1958	540	1,420	1,590	3,550	2.9
1959	1,130	1,410	1,940	4,480	3.7
1960	940	1,440	2,800	5,180	3.9
1961	690	2,400	5,080	8,170	5.1
1962	1,250	1,730	3,170	6,150	4.1
1963	1,090	1,880	2,760	5,730	3.8
1964	550	2,180	2,880	5,610	3.7
1965	400	1,220	1,010	2,630	2.0
1966	1,100	1,850	1,730	4,680	3.2
1967	860	1,580	2,480	4,900	3.5

Analysis of the hydrologic budget

Estimates of variances were made for some of the items of the hydrologic budget for the Vauxhall District for the 10-year period under investigation. The mean and the standard deviation of various items in the hydrologic budget were calculated. These estimates of variance were made using the 95 percent confidence interval limits.

From Table 2, gross delivery and farm delivery as a percentage of the gross diversion was found to be 88.6 ± 3.8 and 68.2 ± 6.3 respectively, on the average, for the 10-year study period. This means that the conveyance loss from diversion to the farm headgate is 31.8 percent. Blaney (8) states that one-third of the diverted water is lost in conveyance and another one-third on the farm itself. From this investigational study it is found that, on the average, for 10-year period the conveyance loss in the Vauxhall District compares with that reported by Blaney.

Consumptive use as a percentage of items of supply is found to be 64.7 ± 4.9 (Table 9). This figure is higher than that reported by other researchers. The consumptive use as reported in the literature varies from 40 to 50% of the items of supply. The reason for this is that potential evapotranspiration figures were used and not the actual consumptive use figures. These figures are for the optimal yields of crops with an adequate amount of water being available at all times.

Irrigation losses as a percentage of items of supply is found to be 35.3±6.2, which means that the project efficiency is about 65 percent. Measured return flow as a percentage of the total irrigation losses is 59.0±12.9. The estimated surface return flow as a percentage of the items of supply was found to be 24.6±5 percent (Table 10a). The measured return flow was 19.7 percent of the items of supply with a confidence interval of 2.0 percent.

The estimated seepage and deep percolation as a percentage of the items of supply is found to have a mean of 7.2 (Table 10a) with a confidence interval of 2.4 percent. Estimated evaporation and evapotranspiration from natural vegetation as a percentage of items of supply is found to have a mean of 3.5 and a standard deviation of 0.85 percent. These figures are the averages for the 10-year period under investigation. These figures are lower than that reported by other researchers (34,42,66). The seepage and deep percolation losses reported were 15 to 20 percent of the items of supply, whereas from this investigational study it is found to be only 7 percent on the average. The evaporation and evapotranspiration is also relatively lower than that reported by Robinson (45).

Some of the items that were of importance were correlated and regression equations of the first order were derived. The equations derived were for precipitation vs gross diversions, gross diversions and precipitation (Items of supply) vs total irrigation losses, gross diversion vs total irrigation losses, farm delivery plus precipitation vs total losses, and total

irrigation loss vs measured return flow. These are shown in Table 17 and graphed as Figures 14 to 18 inclusive.

The correlation between precipitation vs gross diversion correlates negatively with a negative coefficient of 0.63. The correlation coefficient is found to be low and it is not significant. Items of supply vs total losses were significently correlated with a correlation coefficient of 0.80. Farm delivery plus precipitation vs total losses had a correlation coefficient of 0.69 which is not significant. Gross diversion vs total losses had a correlation coefficient of 0.91 which is very significant. Total irrigation loss vs measured return flow gave a correlation coefficient of 0.66 which is not significant.

The regression equations and the graphs show the inter-relation between the various items of the hydrologic budget for the Vauxhall Irrigation District. The most important of these correlations is the gross diversion vs total losses. For a certain amount of diverted water the graph or the regression equation will show the losses to be expected. The equation can be used with some judgement as a guide for similar operating conditions on other irrigation projects.

Table 17: Correlation coefficients and regression equations for various items of the hydrologic budget.

Correlation between	Correlation coefficient, r	Regression equation (y=mx+c)
Precipitation vs gross diversion	-0.63	y=-0.79x+124,200
Items of supply vs total losses	0.80	y=0.78x-58,600
Gross diversions total losses	0.91	y=0.69x-5,400
Farm delivery plus precipitation vs total losses	0.69	y=0.97x-59,600
Total irrigation loss vs measured return flow	0.66	y=0.26x+14,500

Figure 14: Precipitation vs gross diversion.

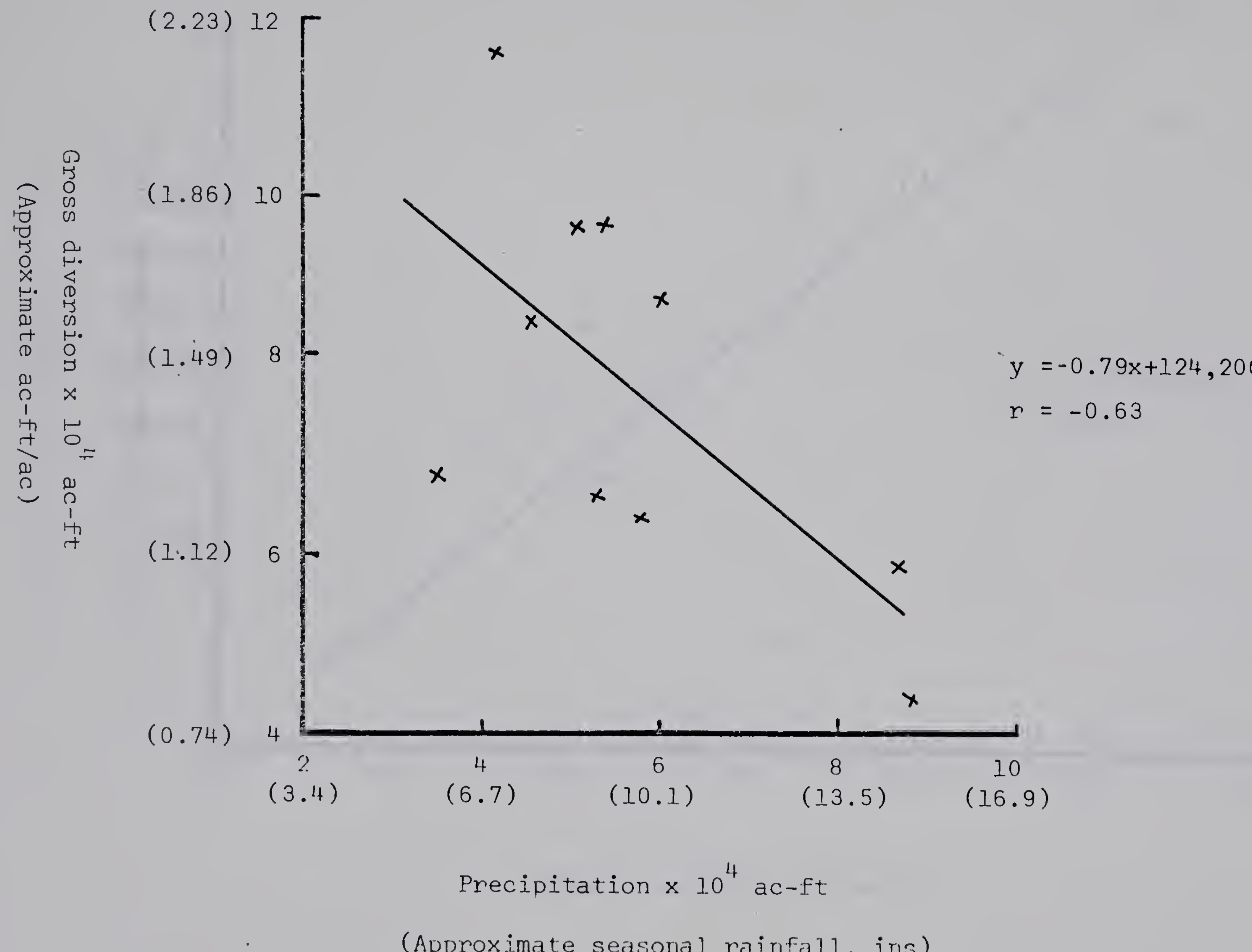


Figure 15: Items of supply vs total irrigation loss.

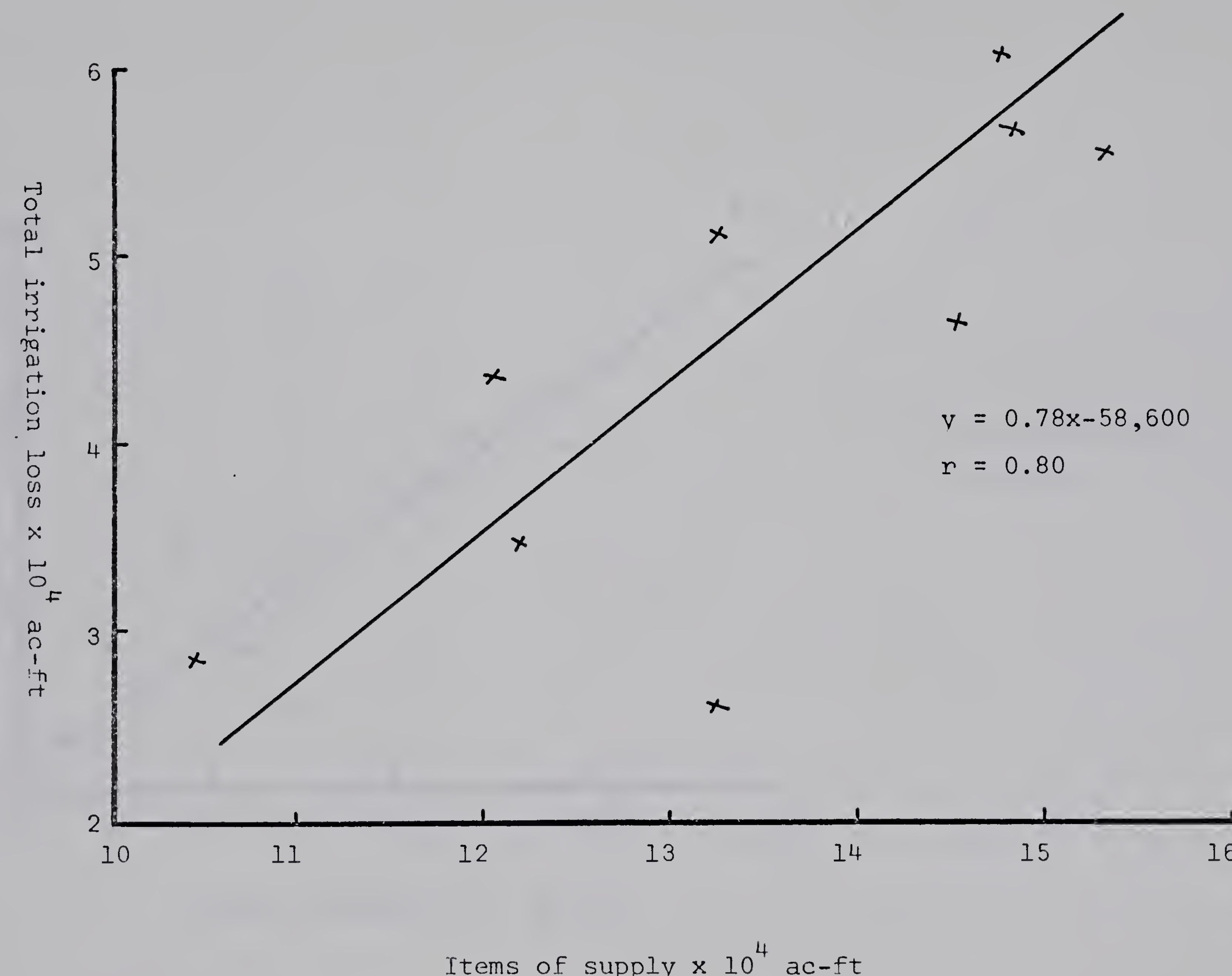


Figure 16: Gross diversion vs total losses.

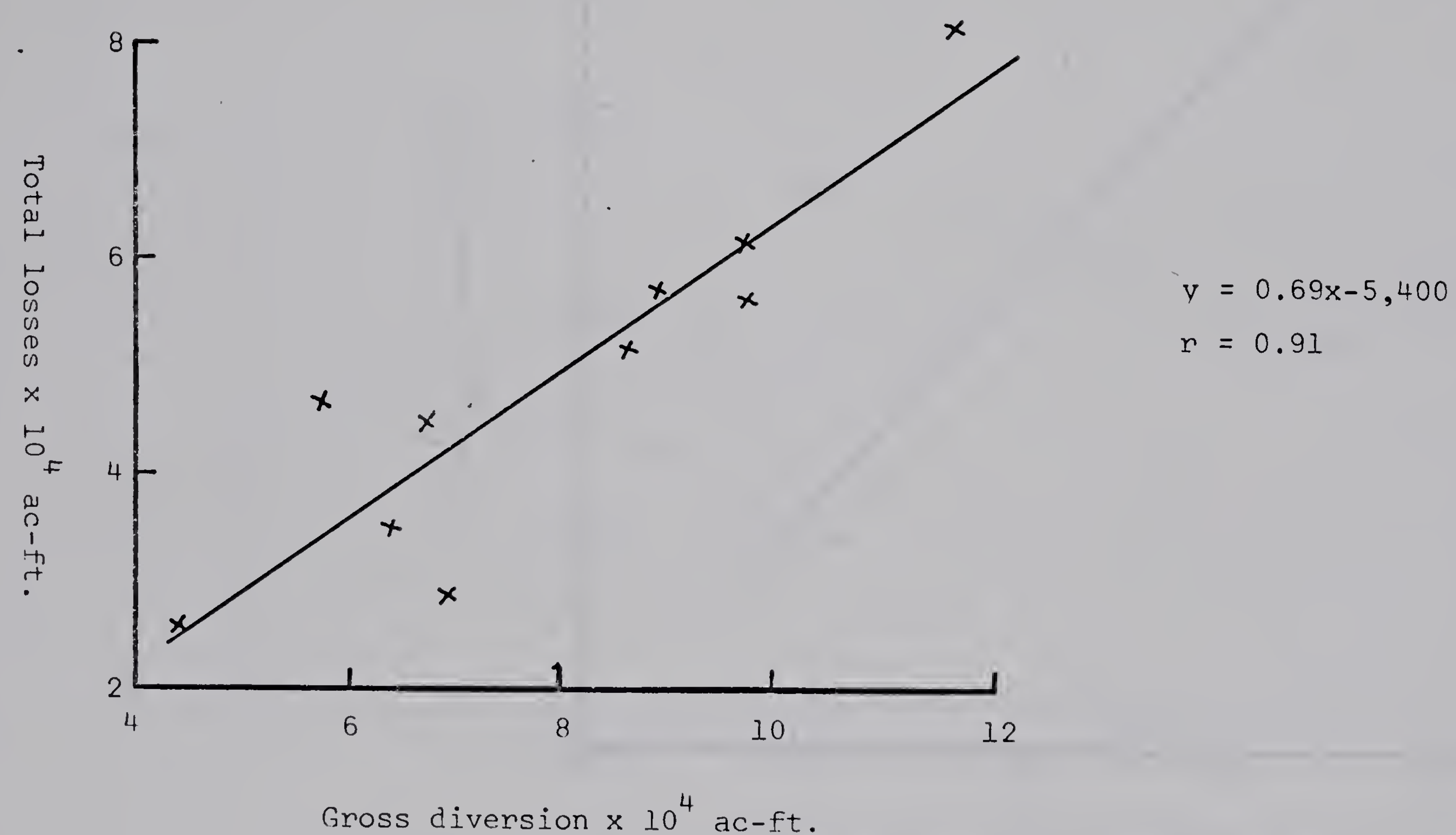


Figure 17: Farm delivery plus precipitation vs total losses.

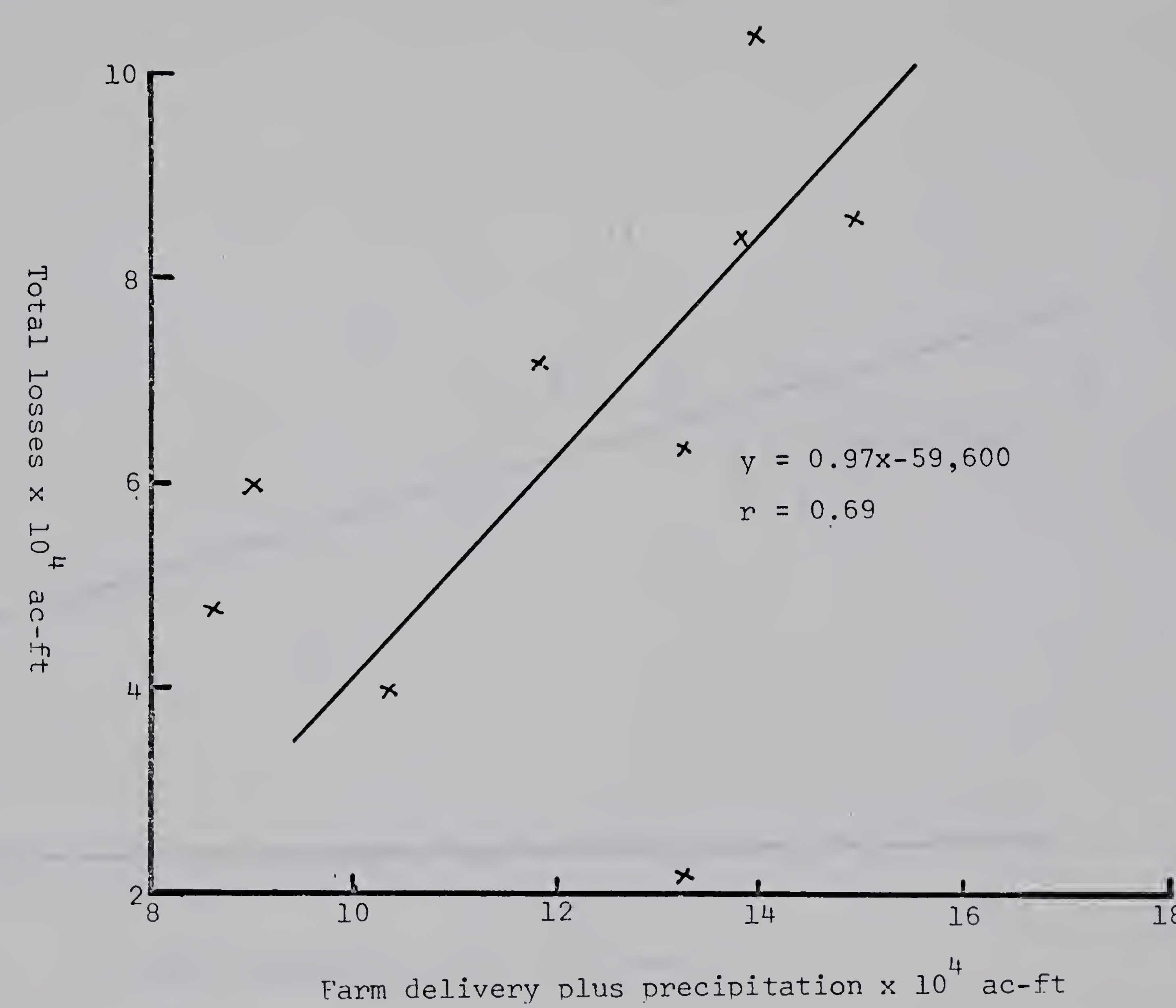
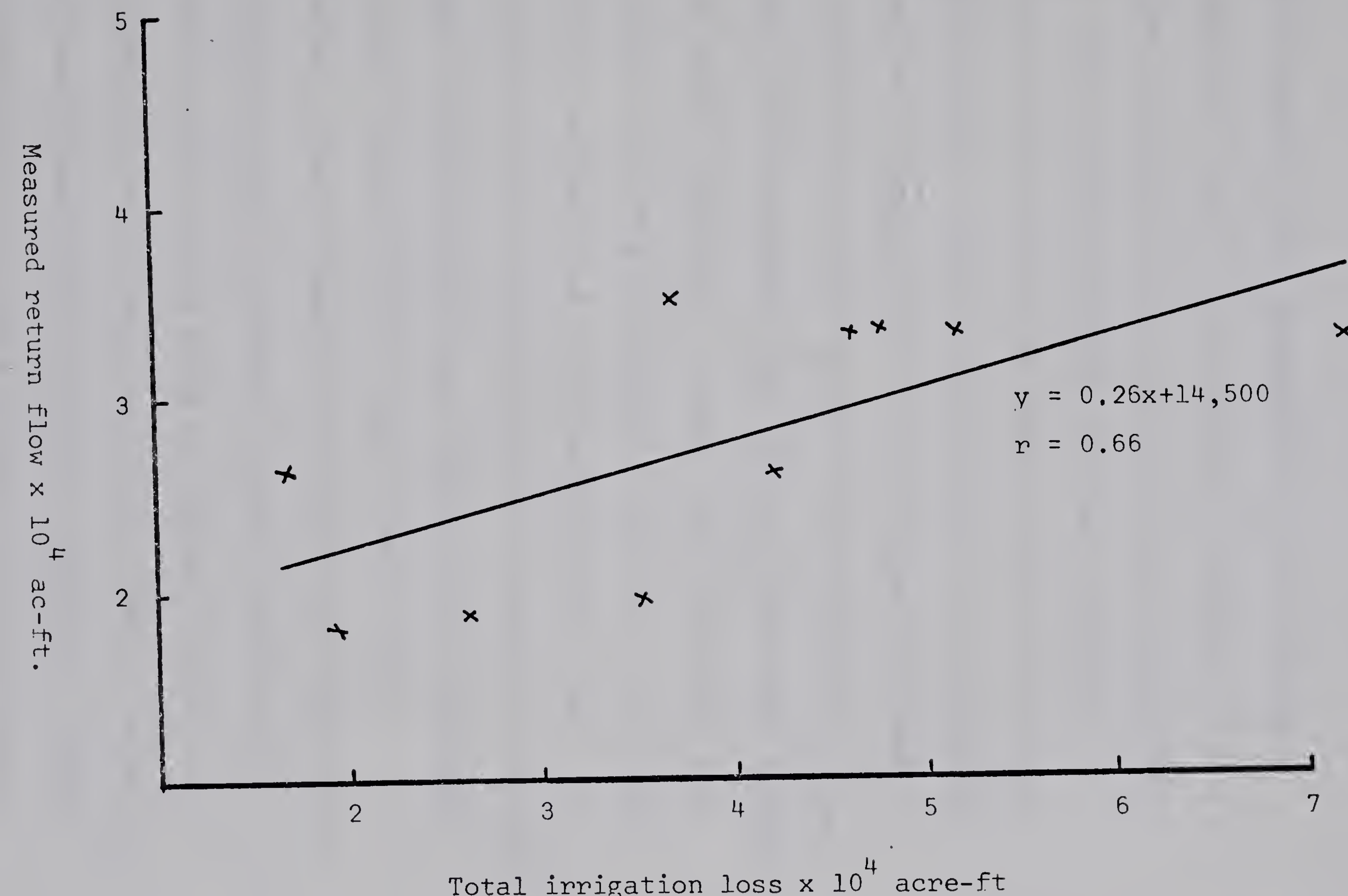


Figure 18: Total irrigation loss vs measured return flow.



SUMMARY AND CONCLUSIONS

1. The purpose of this investigation was to develop a hydrologic budget for the Vauxhall District of the Bow River Irrigation Project for the 10-year period 1957 to 1966 inclusive for which data was available.
2. The data available on the various items of the supply and disposal, such as gross diversion, precipitation, land use, consumptive use and the return flow were collected from several agencies involved in the project. Data on the evaporation loss from the free water surface and natural vegetation, seepage loss from canals and laterals, and deep percolation loss in the farm itself were not available for this investigational study. An estimate was made for any figures that were not available. These estimated figures were compared with the actual measured figures from the Upper Missouri Basin.
3. The main items of supply of the hydrologic budget of an irrigation project consists of gross diversion and precipitation and the items of disposal consists of consumptive use by crops, the surface waste, evaporation and evapotranspiration by natural vegetation, seepage and deep percolation from the Main Canal conveyance, delivery and farm use. All these conveyance and delivery losses are summed under the heading of surface return flow, seepage and deep percolation, and evaporation losses.

4. It is found from this investigational study that approximately 88 percent of the gross diverted water reaches the delivery canals, the remaining percent being the Main Canal loss. Out of this, 68 percent is available to farmers at the farm headgate in addition to the amount available from precipitation.

   In the delivery system 12 percent of the diverted water is lost, while delivering the water from the source of diversion to the farm headgate only 32 percent of the water is lost, which indicates that the project is being used efficiently. Blaney (8) states that one-third of the water diverted is lost in the conveyance to the farm headgate and it can be seen that here too almost one-third of the water is lost in the conveyance system.

5. Considering items of supply to be 100 percent it was found that 64.7 percent of this could be used by crops grown in the Vauxhall District for their optimal growth. This 64.7 percent, on the average, was arrived at by using a mean consumptive use figure for all the years under investigation. However, this does not give the true figure for all the years. In years when the rainfall is below normal the consumptive use figure is high and when the rainfall is above normal it is low, so there is fluctuation.

6. The remaining 35.3 percentage of the items of supply consisting of estimated surface return flow, seepage and deep percolation and evaporation and evapotranspiration from natural vegetation is found to be 24.6, 7.2 and 3.5 percent respectively adding up to 35.3 percent.
7. The data on the measured return flow was compared with the estimated return flow. The measured return flow as a percentage of the items of supply, on the average for the 10-year study period, is found to be 19.7 percent. The estimated surface return flow was higher by 4.9 percent than the measured return flow. The measured return flow was 84 percent of the estimated return flow which is on the average 16 percent higher than the actual measured return flow.
8. Seepage and deep percolation losses and evaporation and evapotranspiration figures as estimated ranged from 3.7 to 10.9 and 2.0 to 5.1 percent respectively of the items of supply.
9. Some of the items of the hydrologic budget were correlated. Precipitation vs gross diversion showed a negative correlation with a correlation coefficient of -0.63 which is not significant. Items of supply vs total losses showed a positive correlation with a correlation coefficient of 0.80 which is significant. Farm delivery plus precipitation vs total losses showed a positive correlation with a coefficient of 0.69. Gross diversion vs total losses correlated significantly with a coefficient of 0.91 and the total irrigation loss vs measured

return flow showed a coefficient of 0.66 which is not significant.

10. Estimates of variance for gross delivery as a percentage of gross diversion was found to be 88.6±3.8 and farm delivery as a percentage of gross diversion was found to be 68.2±6.3. The total irrigation loss as a percentage of items of supply was 35.3±6.2. The estimated surface return flow 59.0±12.9 of the items of supply, the measured return flow 19.7±2.0, estimated seepage and deep percolation 7.2±2.4, and evaporation and evapotranspiration 3.5±0.04. All these estimates were for the 95 percent confidence interval.

11. The most important factor to know while designing a new irrigation project or while improving an old project is to know how much water is needed for the optimal growth of a crop, and how much has to be diverted to supply that amount. From this study it is found for the Vauxhall Irrigation District on the average, 64.7±4.9 percent of the total amount of water supplied can be used consumptively by the crops for their optimal growth, while the remainder is considered as loss. Out of 35.3 percent loss, 24.6 percent flows back to the natural channels as surface return flow and could be used in the lower districts. It is believed that this factor will give good information for irrigation designers

and planners of water use in Southern Alberta. While using this as a guide it must be borne in mind that this finding is for the Vauxhall Irrigation District of the Bow River Project for the 10-year study period 1957-1966 inclusive.

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